

# A *Chandra* Observation of the Nearby Sculptor Group Sd Galaxy NGC 7793

Thomas G. Pannuti<sup>1</sup>, Eric M. Schlegel<sup>2</sup>, Miroslav D. Filipović<sup>3</sup>, Jeffrey L. Payne<sup>3</sup>, Robert  
Petre<sup>4</sup>, Ilana M. Harrus<sup>5</sup>, Wayne D. Staggs<sup>1</sup> and Christina K. Lacey<sup>6</sup>

Received \_\_\_\_\_; accepted \_\_\_\_\_

Accepted for publication in the *Astronomical Journal*

---

<sup>1</sup>Space Science Center, Department of Earth and Space Sciences, Morehead State University, 235 Martindale Drive, Morehead, KY 40351; t.pannuti@moreheadstate.edu, wd-stag01@moreheadstate.edu

<sup>2</sup>Department of Physics and Astronomy, University of Texas-San Antonio, 6900 North Loop 1604 West, San Antonio, TX, 78249-0663; eric.schlegel@utsa.edu

<sup>3</sup>School of Computing and Mathematics, University of Western Sydney, Locked Bag 1797, Penrith South, DC, New South Wales, 1797, Australia; m.filipovic@uws.edu.au, astronomer@me.com

<sup>4</sup>NASA/GSFC, X-ray Astrophysics Laboratory, Code 662, Greenbelt, MD, 20771; robert.petre-1@nasa.gov

<sup>5</sup>NASA/HQ, Astrophysics Division, MS 3W39, Washington, DC 20546-0001; Ilana.M.Harrus@nasa.gov

<sup>6</sup>Department of Physics and Astronomy, Hofstra University, 102 Berliner Hall, Hempstead, NY 11549; Christina.Lacey@hofstra.edu

## ABSTRACT

We conducted a *Chandra* ACIS observation of the nearby Sculptor Group Sd galaxy NGC 7793 as part of a multiwavelength study of supernova remnants (SNRs) in nearby galaxies. At the assumed distance to NGC 7793 of 3.91 Mpc, the limiting unabsorbed luminosity of the detected discrete X-ray sources is  $L_X$  (0.2 – 10.0 keV)  $\approx 3 \times 10^{36}$  ergs s $^{-1}$ . A total of 22 discrete sources were detected at the  $\sim 3\sigma$  level or greater including one ultra-luminous X-ray source (ULX). Based on multiwavelength comparisons, we identify X-ray sources coincident with one SNR, the candidate microquasar N7793-S26, one HII region and two foreground Galactic stars. We also find that the X-ray counterpart to the candidate radio SNR R3 is time-variable in its X-ray emission: we therefore rule out the possibility that this source is a single SNR. A marked asymmetry is seen in the distribution of the discrete sources with the majority lying in the eastern half of this galaxy. All of the sources were analyzed using quantiles to estimate spectral properties and spectra of the four brightest sources (including the ULX) were extracted and analyzed. We searched for time-variability in the X-ray emission of the detected discrete sources using our measured fluxes along with fluxes measured from prior *Einstein* and *ROSAT* observations. From this study, three discrete X-ray sources are established to be significantly variable. A spectral analysis of the galaxy’s diffuse emission is characterized by a temperature of  $kT = 0.19\text{--}0.25$  keV. The luminosity function of the discrete sources shows a slope with an absolute value of  $\Gamma = -0.65 \pm 0.11$  if we exclude the ULX. If the ULX is included, the luminosity function has a long tail to high  $L_X$  with a poor-fitting slope of  $\Gamma = -0.62 \pm 0.2$ . The ULX-less slope is comparable to the slopes measured for the distributions of NGC 6946 and NGC 2403 but much shallower than the slopes measured for the distributions of IC 5332 and M83. Lastly, we comment on the multi-wavelength

properties of the SNR population of NGC 7793.

*Subject headings:* galaxies: individual (NGC 7793) – galaxies: spiral – X-rays: galaxies  
– X-rays: supernova remnants – X-rays: binaries

## 1. Introduction

Based on its superior angular resolution capabilities – namely, an on-axis point spread function (PSF) with a half-power diameter of  $\sim 1''$  – the *Chandra* X-ray Observatory (Weisskopf et al. 2002) is an ideal instrument for surveying populations of discrete X-ray sources in nearby spiral galaxies. To date, numerous nearby spiral galaxies have been the subjects of deep *Chandra* observations which have sampled their resident X-ray source populations in unprecedented detail. Prominent examples of such galaxies which have been the subject of such studies include M33 (Plucinsky et al. 2008; Long et al. 2010; Tuellmann et al. 2011), M51 (Terashima & Wilson 2001, 2004), M81 (Swartz et al. 2003), M83 (Soria & Wu 2003), M101 (Pence et al. 2001; Mukai et al. 2003), NGC 1637 (Immler et al. 2003), NGC 2403 (Schlegel & Pannuti 2003), NGC 3184 (Kilgard et al. 2002), NGC 6946 (Holt et al. 2003) and IC 5332 (Kilgard et al. 2002). In each case, the *Chandra* observations have dramatically increased the numbers of known discrete X-ray sources in each galaxy. The applications of these observations include sampling a robust number of discrete X-ray sources for statistically-significant analyses, spatially resolving the discrete sources from a component of diffuse X-ray emission detected from some galaxies, spectral analyses of the brightest discrete sources, time variability analyses (often incorporating observations made with previous X-ray observatories) and measurement with high accuracy of the positions of X-ray sources for the purposes of identifying counterparts at other wavelengths.

Typically, the classes of X-ray objects detected by these surveys include X-ray sources associated with active galactic nuclei (AGN), X-ray binaries (XRBs) and supernova remnants (SNRs). Observations of XRBs and SNRs are essential in developing a thorough understanding of stellar evolution. Unfortunately, studies of XRBs and SNRs in our own Galaxy are hampered by observational difficulties, including significant absorption along

Galactic lines of sight as well as considerable uncertainties in distances to these sources. In addition, the Galactic population of XRBs and SNRs represent a galaxy of a single mass, metallicity, star formation history and morphological type. Observing XRBs and SNRs located in nearby galaxies minimizes these issues. In prior works (Pannuti et al. 2000; Lacey & Duric 2001; Pannuti et al. 2002, 2007; Filipović et al. 2008), we analyzed high angular resolution observations at multiple wavelengths of several nearby galaxies to both identify SNRs and statistically assess their properties. In the present paper we continue this work by analyzing a *Chandra* observation of the nearby Sd galaxy NGC 7793. This observation was conducted primarily to study X-ray emission from the SNR population in NGC 7793; here we consider the properties of the discrete X-ray sources detected in this galaxy as well as the accompanying diffuse X-ray emission.

NGC 7793, a member of the nearby Sculptor Group (Puche & Carignan 1988), lies at a distance of 3.91 Mpc (Karachentsev et al. 2003) and at an inclination angle of  $i \sim 50^\circ$  (Tully 1988). General properties of both NGC 7793 and the pointed *Chandra* observation of this galaxy are listed in Table 1. NGC 7793 has been the subject of prior X-ray observations made with the *Einstein* Imaging Proportional Counter (IPC) (Fabbiano et al. 1992) and the *Röntgensatellit* (*ROSAT*) Position Sensitive Proportional Counter (PSPC) (Read & Pietsch 1999, hereafter RP99). These observations detected seven X-ray sources – including an ultra-luminous X-ray source (ULX) located along the southern edge of the galaxy – within the optical extent of NGC 7793. In addition, prominent diffuse X-ray emission which permeates much of the disk of the galaxy has been detected (RP99). The SNR population of NGC 7793 has been well-studied by both optical and radio surveys (Blair & Long 1997; Pannuti et al. 2002); based on these searches, a total of 32 resident SNRs have been identified in this galaxy. In the present paper, we will concentrate on searching for X-ray counterparts to these 32 sources. N7793-S26 – an additional source that was initially classified as a SNR by Blair & Long (1997) and detected in the radio

by Read & Pietsch (1999) and Pannuti et al. (2002) – has recently been classified as a microquasar candidate by Pakull et al. (2010) and Soria et al. (2010). We exclude this source from our investigation presented here of the properties of SNRs in NGC 7793 and we will discuss this source (particularly its X-ray, optical and radio properties when compared to extragalactic superbubbles) in more detail in a future paper.

The organization of this paper is as follows: the observations and data reduction are described in Section 2. Properties of the discrete X-ray sources detected by this observation – including spectral analysis of four of the most luminous sources as well as searches for multi-wavelength counterparts and time-variable emission from all sources – are discussed in Section 3. Next we discuss the diffuse X-ray emission from NGC 7793 as sampled by this observation (Section 4), the luminosity function of the discrete sources (Section 5) and the properties of the SNR population of this galaxy (Section 6). Finally, we summarize our results in Section 7.

## 2. Observations and Data Reduction

We used the Advanced Charge-Coupled Device (CCD) Imaging Spectrometer (ACIS) (Garmire et al. 2003) onboard *Chandra* to observe NGC 7793. The observation was obtained in Very Faint mode on 2003 September 6-7 using an aim point approximately two arcminutes west of the nucleus, ensuring the maximum coverage of NGC 7793 across the (back-illuminated) ACIS-S3 chip. The exposure lasted approximately 49724 seconds and, after correcting for the deadtime, the effective exposure time was 49094 seconds.

We accumulated source-free background areas offset from the galaxy (namely from the back-illuminated ACIS-S1 chip) and extracted a light curve using 50-second bins to test for the presence of soft background flares. No flaring behavior of any kind was detected.

We re-filtered the Level 1 data, correcting for the induced charge-transfer inefficiency following the prescription of Townsley et al. (2000). This approach permits using a single event redistribution matrix in the spectral fitting, altering the response matrix for the off-axis-dependent effective area. The data was reduced with standard tools in the software application package “*Chandra* Interactive Analysis of Observations” (*CIAO*<sup>1</sup>) Version 3.4 (CALDB version 3.3.0).

Point sources were identified using `wavdetect` at 1'', 2'', and 4'' scales (Freeman et al. 2002). The detected sources were merged into a final source list after eliminating duplicate detections. Source counts were extracted using apertures that increased with off-axis angle to ensure the inclusion of an approximately constant fraction of the PSF. The minimum aperture was 2'' in diameter and enclosed >95% of the PSF. These same apertures were used to extract spectra (see Section 3.1) or counts for quantiles (see Section 3.3), depending upon the count rate. A background spectrum was obtained from a region on the ACIS-S3 chip but outside of the galaxy and southeast of the nucleus.

### 3. The Discrete X-ray Source Population

We detected 22 discrete X-ray sources within the optical extent of NGC 7793 at the  $\sim 3\sigma$  level or greater to a limiting unabsorbed luminosity of approximately  $L_X \approx 3 \times 10^{36}$  ergs s<sup>-1</sup> over the energy range of 0.2 through 10.0 keV, assuming a foreground column density of  $N_H = 1.15 \times 10^{20}$  cm<sup>-2</sup> and a power law model with a photon index  $\Gamma=1.5$ . Table 2 lists the properties of these sources, including position (in J2000.0 coordinates), absorbed and unabsorbed fluxes, unabsorbed luminosities and the significance (in  $\sigma$ ) of the detection

---

<sup>1</sup>See <http://cxc.harvard.edu/ciao/> and Fruscione et al. (2006).

of the source. In Figure 1, we present an R-band image<sup>2</sup> of NGC 7793 with the positions of the detected X-ray sources indicated with ellipses representing the 90% confidence contours of their measured positions. The sizes of these ellipses are related to the errors in the determination of the source positions. In comparison, the *ROSAT* PSPC revealed seven discrete sources (RP99). Similar to the previous X-ray observations (Fabbiano et al. 1992, RP99), we have not detected a central X-ray source associated with the nucleus of this galaxy to the stated limiting unabsorbed luminosity. We expect that the majority of the detected sources are resident XRBs; other possibilities include background AGNs, foreground stars, and X-ray luminous SNRs. Table 3 lists identified counterparts to the X-ray sources as detected at multiple wavelengths: we discuss each of these associations in detail in Sections 3.1 and 3.2. Lastly, Table 4 contains the spectral properties of the entire population of discrete X-ray sources based on quantiles; these properties will be discussed in more detail in Section 3.3.

Inspection of Figure 1 reveals a remarkable asymmetry in the distribution of the discrete X-ray sources with the large majority of the discrete sources located in the eastern half of NGC 7793. Only four of the 22 discrete X-ray sources are found in the western half and there is a stark absence of discrete sources in the northwestern quadrant. Previous *Einstein* and *ROSAT* observations (Fabbiano et al. 1992, RP99) also did not detect any discrete sources in this quadrant. We discuss this asymmetry more thoroughly in Section 3.5.

---

<sup>2</sup>The R-band image has been kindly provided to us by Annette M. N. Ferguson: for details on the observations of this galaxy that produced this image, the reader is referred to Ferguson et al. (1996).



### 3.1. The Most Luminous Discrete Sources

For four of the 22 discrete X-ray sources, there were sufficient counts above our arbitrary limit of 200 counts (corresponding to a count rate of  $\sim 4 \times 10^{-3}$  counts per second) to extract spectra and generate spectral fits that yielded parameters which were measured to  $< 30\%$ . We now discuss general properties of each of these four sources: properties of the other discrete sources are presented in Section 3.2. In each case, the spectra were fit using the software package *XSPEC* Version 11.3.1 (Arnaud 1996)<sup>3</sup>: the individual spectra were grouped to a minimum of 25 counts per bin and each spectrum was fit over the energy range where there were a sufficient number of counts. We have not performed any fits to the X-ray spectrum of the source CXOU J235752.7–323309 even though the number of counts detected from this source exceed the threshold stated above because this source is physically associated with a foreground star (see Section 3.2).

We used four basic models to fit each extracted spectrum: a simple power law model, a bremsstrahlung model (Karzas & Latter 1961; Kellogg et al. 1975), the APEC model, an optically thin thermal plasma model known as the APEC model (Smith et al. 2001), and finally the DiskBB model (Mitsuda et al. 1984; Makishima et al. 1986). This last model describes the spectrum from an accretion disk consisting of multiple blackbody components and is characterized by the temperature  $T_{in}$  at the inner disk radius. To account for photoelectric absorption along the line of sight we used the Wisconsin cross-section models (Morrison & McCammon 1983). There are two choices possible when fitting the column density: fixing it at the value of the known Galactic column density in the pointing direction (that is,  $N_H = 1.15 \times 10^{20} \text{ cm}^{-2}$ ) or treating it as a free parameter. With this in mind, we performed fits to the extracted spectra using the four models first with the column density frozen to the known Galactic column and then with the column density left

---

<sup>3</sup>Also see <http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/>.

as a free parameter. Lastly, a background spectrum was extracted using an aperture 0.7 arcmin in diameter and positioned off the optical extent of the galaxy. No point sources were included in this aperture. The resulting spectrum extracted from this aperture was accurately fit using a combination of a power law component and Gaussians. In Table 4, we present a representative summary of our derived best fits and not the results of every fit that we attempted obtained for each model. The background spectrum itself and best-fit model were then included in the fits to each point source without adjusting the background model fit components.

In general, the basic models return statistically acceptable fits for each source. In some cases, a particular spectrum warranted a more complex model to obtain a satisfactory fit. Also, in some cases significant statistical differences in the fits were seen when the column density was frozen or thawed: below we discuss specific results for fitting the extracted spectra. The spectra of two of these sources were also analyzed by RP99: we also compare our derived fits with the fits obtained by those authors.

*CXOU J235746.7–323607*: This source corresponds to the X-ray source P10 identified by RP99 and the candidate radio SNR R3 identified by Pannuti et al. (2002): the offset between CXOU J235746.7–323607 and P10 is  $\sim 6''$  while the offset between CXOU J235746.7–323607 and R3 is only  $\sim 1.5''$ . Pannuti et al. (2002) proposed that this X-ray source and the candidate radio SNR are physically associated based on their positional proximity. RP99 commented on the soft nature of the *ROSAT* PSPC spectrum of this source. Based on this soft spectrum, a lack of apparent variability in the X-ray emission (between two epochs of *ROSAT* observations) and its positional association with a portion of NGC 7793 that features numerous SNRs, RP99 speculated that this X-ray source may be a superbubble or the collective X-ray emission from multiple SNRs.

Our fits indicate a moderately-hard spectrum for this source. The bremsstrahlung

temperature is higher than that of RP99 ( $kT \sim 1.6$  keV compared to  $kT \sim 0.8$  keV), although the error bars overlap the fitted values. The fitted temperature obtained from the DiskBB model is softer ( $kT \sim 0.7$  keV): the use of the DiskBB model in this case – while physically less appropriate for a source identified as an SNR, is justified below. Within the errors, the fitted column density is consistent with the known column toward NGC 7793. If we fix the column density to the known column, the impact is largely confined to the power law model: the power law index  $\Gamma$  falls from 2.9 to 1.7 with a slight overlap in the error bars; for the other models, the fitted parameters differ by  $<10\%$ . All models (with the exception of the APEC model) require the addition of two zero-width Gaussians to model line-like features. The Gaussians have line centers at 0.94 and 1.46 keV and the equivalent widths of these lines are largest in the power law model, with values of 111 and 102 eV, respectively.

The normalization of the DiskBB model is defined as  $[(R_{\text{in}}/\text{km})/(D/10 \text{ kpc})]^2$  where  $R_{\text{in}}$  is the inner disk radius in km and  $D$  is the distance to the source in units of 10 kpc. The fitted normalization then corresponds to  $26^{+73}_{-17}$  km, a value larger than is generally deemed typical of neutron stars but falling within inferred radii of other low-mass X-ray binaries (e.g., Church & Balucinska-Church (2001)). In Figures 2 and 3 we present the extracted spectrum of CXOU J235746.7–323607 as fit with the power law model (with a variable column density) and a confidence contour plot for this fit, respectively.

We note that we have detected a clear variability in the X-ray emission from this source. The prior *ROSAT* PSPC observations of this galaxy reported by RP99 caught this source in a brighter state than our *Chandra* observation by a factor of approximately three. This time-variability – coupled with the high X-ray luminosity and the moderately hard spectrum observed for this source – cast doubt on the classification of this source as a single SNR. Alternatively, CXOU J235746.7–323607 may be an SNR/XRB system analogous

to the Galactic source W50/SS 433 (Safi-Harb & Petre 1999), though the observed X-ray luminosity of the former source is several orders of magnitudes greater than the latter source. It is possible that the observed X-ray emission stems from a complex of sources which remain unresolved even with the high angular resolution capabilities of *Chandra*. The classification of CXOU J235746.7–323607 is therefore currently uncertain and we will discuss this source again in Section 3.4 when we discuss a search for time-variability in the X-ray emission from the detected discrete X-ray sources and in Section 6 when we describe properties of the SNR population of this galaxy.

*CXOU J235750.9–323726*: This source, suspected to be a ULX associated with NGC 7793, was identified as P13 by RP99. Those authors presented a detailed history and an analysis of its spectral properties. To summarize, this source was first detected by *Einstein* (Fabbiano et al. 1992) and subsequently Margon et al. (1985) included it in an atlas of X-ray selected quasi-stellar objects, arguing that the source was associated with a background quasar seen just below the southern edge of NGC 7793. This quasar has been cataloged as 2355–329 and features a redshift of 0.071. It has also been cataloged as 2355–3254 in more recent observations presented by Bowen et al. (1994). The *Einstein* observation localized the position to within an arcminute; with the better angular resolution of the *ROSAT* PSPC, RP99 ruled out an association between P13 and the background quasar, arguing instead that the X-ray source is native to NGC 7793. RP99 described time variability in the source’s emission by comparing observations made six months apart and speculated that the source may be either a background galaxy or a black hole X-ray binary with an estimated mass of  $\sim 10 M_{\odot}$ . The estimated X-ray luminosity of this source ( $\sim 10^{39}$  ergs s $^{-1}$ , assuming that it is in fact associated with NGC 7793) is comparable to ULXs seen in other galaxies.

Our *Chandra* observations verify that this source is indeed located within the optical

extent of NGC 7793. We used the improved positional accuracy to search for a counterpart using optical ( $H\alpha$  and R-band) images and our radio maps of NGC 7793 (Pannuti et al. 2002) but we do not find a clear optical or radio counterpart. Recently, Motch et al. (2011) identified an optical counterpart (a  $V \sim 20.5$  magnitude star) and suggest this star (a late B-type supergiant with a mass between 10 and 20  $M_{\odot}$ ) to be the companion star to the observed X-ray source.

RP99 derived fits to their extracted *ROSAT* PSPC spectrum of this X-ray source using either a thermal bremsstrahlung model with a characteristic temperature  $kT = 3.49^{+4.26}_{-3.49}$  keV or a power law model with a photon index  $\Gamma \sim 1.8 \pm 0.5$ . We do not derive a statistically-acceptable fit for any models if the column density is fixed to the Galactic value. The derived column densities from our fits were  $N_H \sim 10^{21} \text{ cm}^{-2}$ , nearly a full order of magnitude greater than the nominal column density toward NGC 7793 itself. Compared with the fit presented by RP99, our fit with a bremsstrahlung model returns a significantly higher effective temperature ( $kT > 14$  keV). A portion of the discrepancy may be explained by the broader energy range sampled by the *Chandra* spectrum; alternatively, a spectral state change is also possible. The photon index derived by our power law fit ( $\Gamma = 1.4^{+0.20}_{-0.18}$ ) is consistent with the value derived by RP99. From the DiskBB model, our derived inner disk radius temperature of  $kT_{in} = 1.83^{+0.24}_{-0.18}$  keV is consistent with a stellar-mass black hole XRB. The DiskBB model yields a low value for the column density ( $N_H = 0.09^{+0.02}_{-0.05} \times 10^{22} \text{ cm}^{-2}$ ): this value is consistent with the column values of RP99. Figures 4 and 5 show the extracted spectrum of CXOU J235750.9–323726 as fit with the DiskBB model and a confidence contour plot for this fit, respectively.

We also note that *Chandra* has revealed for the first time a second source located  $\sim 2''$  east of the CXOU J235750.9–323726. This second source is denoted as CXOU J235750.9–323728 and it is an order of magnitude less luminous than the ULX. CXOU

J235750.9–323726 and CXOU J235750.9–323728 are approximately  $5''$  and  $8''$  respectively from the position given by RP99 for P13. These sources would certainly be blended by the broader PSF of the *ROSAT* PSPC ( $\sim 27''$ ).

*CXOU J235806.6–323757.* The *Chandra* detection of this source immediately establishes it as a variable – given its measured luminosity, it should have been detected during the prior *ROSAT* observations. The spectral models all return equally acceptable fits: an order-of-magnitude higher column density than the known Galactic value is required for fits with the bremsstrahlung model and the power law model while the DiskBB model only requires a column of  $N_H < 8 \times 10^{20} \text{ cm}^{-2}$ . The bremsstrahlung temperature is  $kT \sim 2$  keV but rises to  $kT \sim 6.4$  keV if the column density is fixed at the known value; otherwise, the parameters of the fixed column models change insignificantly. All models require an unresolved line at 0.83 keV with equivalent widths that range from 45 to 122 eV. The bremsstrahlung and power law models require a second unresolved line at 0.67 keV with an equivalent width of  $\sim 120$  eV. The combination of spectral fit values and variability suggests an XRB classification is the most likely for this source. Figures 6 and 7 present the extracted spectrum of this source as fit with the power law model (with a thawed column density) and a confidence contour plot for this fit, respectively.

*CXOU J235808.7–323403.* The offset between this source and RP99 source P9 is approximately  $\sim 2''$ , so we claim that these sources are in fact the same. This source is the weakest source of the four considered in this Section for which a basic spectral analysis is reasonable. The three best-fit models are listed in Table 4; none of them is particularly good as single high (or low) bins contribute relatively large values to  $\chi^2$ . We do not include other models as the fits are significantly poorer. The spectrum is clearly soft for all three fits, which overlap within the errors. Given the relatively poor fit, the flux is likely an overestimate and the errors on the normalization appropriately reflect the uncertainty.

RP99 note that this source, which corresponds to P9 in their paper, is variable and highly absorbed. If we adopt the best-fit APEC model, we confirm the high absorption as two of the fits yield column densities with values of  $N_H \sim 0.1\text{--}0.2 \times 10^{22} \text{ cm}^{-2}$ . As with RP99, we do not detect a counterpart at optical or radio wavelengths. In Figure 8 we present the extracted spectrum for this source as fit with the APEC model.

### 3.2. Identifications of Other Discrete X-ray Sources

We now briefly comment on the nature of some of the other *Chandra*-detected X-ray sources. We searched at multiple wavelengths for counterparts to these sources: we also identified sources which may have been confused in prior X-ray observations due to poorer angular resolution. We recount the results of these searches here and present a summary of these counterparts in Table 3.

*Foreground Stars:* The optical counterparts of CXOU J235748.6–323234 and CXOU J235752.7–323309 are foreground stars. The first source corresponds to the star USNO 0574–1250312 (Monet et al. 2003): it was previously detected with the *ROSAT* PSPC by RP99 and was labeled by those authors as P6. The offset between P6 and our *Chandra* position is  $4.2''$ ; *Chandra*’s improved position yields an offset from USNO 0574–1250312 of only  $1.3''$ . Davoust & de Vaucouleurs (1980) noted that the star USNO 0574–1250312 was misclassified as an HII region (#18) by Hodge (1969).

The second source matches the source cataloged as P7 by RP99 with a *Chandra-ROSAT* position offset of  $\sim 2''$ . We therefore claim that the two sources are in fact the same. RP99 speculated that this source may be a background object; we instead claim that this source is physically associated with the star USNO 0574–1250339 (Monet et al. 2003), located only  $0.8''$  from the *Chandra* position.

*HII Regions:* Catalogs of HII regions in NGC 7793 have been presented by Hodge (1969) and Davoust & de Vaucouleurs (1980). We used a search radius of  $3''$  to identify associations between our *Chandra* sources and the cataloged HII regions. We found one such association: the X-ray source CXOU J235743.8–323633 is offset from the HII region D22 (Davoust & de Vaucouleurs 1980) by  $2.5''$ ; we suggest that these two sources are physically associated. This X-ray source may be an SNR or an XRB associated with the HII region as we do not generally expect H II regions to be X-ray luminous.

*SNRs:* As described previously, a total of 32 optically-identified SNRs and candidate radio SNRs have been identified in NGC 7793 based on the optical (Blair & Long 1997) and radio searches (Pannuti et al. 2002). We have already discussed the association between the X-ray source CXOU J235746.7–323607 and the candidate radio SNR R3 (§3.1). If we adopt a search radius of  $1.5''$  (which corresponds to a linear distance of approximately 30 pc at the assumed distance to NGC 7793), we find one other association<sup>4</sup>. This association (with an offset of  $1.1''$ ) occurs between CXOU J235747.2–323523 and the optically-identified SNR S11 (Blair & Long 1997). This source had been originally classified as an HII region (#40) by Davoust & de Vaucouleurs (1980). Pannuti et al. (2002) found a non-thermal radio counterpart, which helped to solidify its classification as an SNR. The *Chandra* observation clearly reveals an X-ray counterpart for the first time, making it one of a small number of known extragalactic SNRs which have been detected at X-ray, optical and

---

<sup>4</sup>We note here that the published positions of several candidate radio SNRs detected in NGC 7793 by Pannuti et al. (2002) are in error and give the correct positions here (RA units = hours, minutes and seconds; Dec units are degrees, arcminutes and arcseconds): NGC 7793-R1 – RA (J2000.0): 23 57 40.2, Dec (J2000.0): –32 36 38; NGC 7793-R4 – RA (J2000.0): 23 57 48.2, Dec (J2000.0): –32 36 15; NGC 7793-R5 – RA (J2000.0): 23 58 00.6, Dec (J2000.0): –32 35 06.



radio wavelengths. We will discuss the multi-wavelength properties of the SNR population of NGC 7793 in more detail in Section 6. For completeness, we also note that within this adopted search radius, our cataloged source CXOU J235800.1–323325 is coincident with the southern component of the candidate microquasar N7793-S26. As mentioned earlier, this source was previously classified as an SNR (Blair & Long 1997; Pannuti et al. 2002) but has recently been re-classified as a microquasar (Pakull et al. 2010; Soria et al. 2010): CXOU J235800.1–323325 features some spatial extent in the X-ray that mimics the observed extended emission seen at optical and radio wavelengths.

*Young Massive Star Clusters:* We searched for positional coincidences between our sample of X-ray sources and the 20 young massive star clusters identified in this galaxy by Larsen & Richtler (1999) and Larsen (1999). The effective radii of these clusters were given by Larsen (1999) and range from  $\sim 4$ –60 pc at our assumed distance to NGC 7793 (corresponding to a projected angular scale of  $0.3$ – $3''$ ). Using these radii, our search found no positional matches.

*Background Sources:* We also used the NASA/IPAC Extragalactic Database (NED<sup>5</sup>) to search for background source counterparts for the remaining eleven discrete X-ray sources identified in our survey. We adopted a radius of  $6''$  for this search but no counterparts were identified for any of the eleven sources. To estimate the number of detected background sources that are seen in projection beyond NGC 7793, we use the relation given by Campana et al. (2001) for the number  $N$  of background sources greater than a flux density  $S$  per square degree, which may be expressed (in CGS units) as

$$N ( > S ) = 360 \left( \frac{S}{2 \times 10^{-15}} \right)^{-0.68}. \quad (1)$$

---

<sup>5</sup>Available on the World Wide Web at <http://nedwww.ipac.caltech.edu>.

If we consider the entire ACIS-S3 chip (with a field of view of  $8.3' \times 8.3'$ ) and assume a limiting absorbed flux of  $1.15 \times 10^{-15}$  ergs  $\text{cm}^{-2}$   $\text{s}^{-1}$  for our observation, we estimate that approximately ten background sources lie within those bounds. NGC 7793 covers approximately half of the ACIS-S3 chip, so we adopt a contamination of  $\sim 5$  background objects within the optical extent of the galaxy.

*Sources Previously Blended and Now De-Blended by Chandra:* Finally, we describe our search for sources which may have been blended by previous observations but have been resolved with *Chandra*. Besides the resolved emission components from the candidate microquasar N7793-S26, we find two such instances: the first includes the two X-ray sources found within the error circle of the source P13, the ULX, discussed previously. The second instance involves the sources CXOU J235802.8–323614 and CXOU J235803.54–323643 which are located within  $20''$  and  $11''$ , respectively, of the position of the source P11 identified by RP99. The latter source is only slightly more luminous than the former and it appears that the combination of emission from both were identified as P11 in the PSPC observation.

### 3.3. Quantile Analysis of the Spectral Properties of the Discrete X-ray Sources

We adopted the quantile approach to a color-color diagram (Hong et al. 2004). The quantile method determines the energy below which a fixed percentage of events fall: colors are therefore determined from the ratios or differences of the resulting energies. Briefly,  $E_X$  is defined as the energy below which the net counts are  $X\%$  of the total net counts;  $E_{25}$ ,  $E_{50}$  and  $E_{75}$  then correspond to the energies below which the counts are 25%, 50% and 75%, respectively, of the total counts. Further, the quantile  $Q_X$  is defined as

$$Q_X = \frac{E_X - E_{low}}{E_{high} - E_{low}} \quad (2)$$

where  $E_{low}$  and  $E_{high}$  are the lower and upper boundary energies respectively of the full energy band considered (in the present paper, we have assumed values of  $E_{low} = 0.2$  keV and  $E_{high} = 10.0$  keV). The grid is defined by  $3^*(Q_{25}/Q_{75})$  versus  $\log (Q_{50}/(1-Q_{50}))$  to separate the data as much as possible. The appearance of the interpretative grid in model coordinates (e.g.,  $N_H$  versus  $kT$ ,  $N_H$  versus power law index) has a quashed appearance, reflecting the spectral energy information truly available from the instrument. The reader is referred to Hong et al. (2004) for more information about the quantile approach.

Calculated values for  $Q_{25}$ ,  $Q_{50}$ ,  $Q_{75}$ , and  $3^*(Q_{25}/Q_{75})$  are presented in Table 5. For example, in the case of the first tabulated source CXOU J235743.8–323633, we have measured a value for  $E_{25} = 1.14$  keV and the corresponding value for  $Q_{25}$  is 0.096. In Figures 9 and 10 we present the quantile grids for the optically-thin gas model APEC and power law models, respectively. For both grids, moving vertically in the grid crosses lines of equal  $N_H$  with values of 0.001 (bottom), 0.01, 0.05, 0.1, 0.5, 1.0 and  $5.0 \times 10^{22}$  cm $^{-2}$  (top). The APEC temperature  $kT$  increments horizontally with values of 0.2 (left), 0.4, 1.0, 2.0, 5.0, and 10.0 keV (right). The power law photon indices include grid values of 0.5 (left), 1.0, 1.5, 2.0, 2.5, 3.0, and 5.0 (right).

We have assumed a foreground Galactic column density toward NGC 7793 of  $N_H = 1.15 \times 10^{20}$  cm $^{-2}$ : this value corresponds to a line of constant  $3^*(Q_{25}/Q_{75})$  of  $\sim 1$ . If we momentarily ignore the error bars, the plots show approximately two distinct groups: three points located near  $(\log Q_{50}/(1-Q_{50}), 3^*(Q_{25}/Q_{75})) \sim (-1.2, 1.8)$  (which we shall denote as Group (i)) and a group located at  $\sim (-0.9, 1.0)$  (which we shall denote as Group (ii)). Considering Group (ii) first, we note that this group contains a mix of sources: the counterpart to the HII region D2 (CXOU J235743.7–323633), the X-ray

counterpart to the candidate radio SNR R3 (CXOU J235746.7–323607), the probable ULX (CXOU J234750.8–323726), two foreground stars (CXOU J235748.6–323234 and CXOU J235752.7–323309, which are associated with USNO 0574-1250312 and USNO 0574–1250339, respectively), and potentially about five background AGNs. The Group (ii) sources are broadly consistent with the column density toward NGC 7793: sources in this group are also consistent with hard emission as indicated by their positions in both quantile plots.

The three sources that belong to Group (i) are CXOU J235747.2–323523 (the X-ray counterpart to the SNR N7793-S11 as discussed in Section 3.2), CXOU J235800.1–323325 and CXOU J235800.3–323455. While the identification of the X-ray counterpart to N7793-S11 seems clear, there are several possible physical interpretations possible for other the sources that belong in Group (i). If an H II region contains an SNR, then the separation of the Group (i) points from the H II regions in Group (ii) may result from the strong line emission present in the spectrum of the SNR; the excess absorption could be explained as circumstellar matter or recombining nucleosynthesized matter. Alternatively, if the H II region contains the remains of a massive star, the emission would be expected to be much harder if dominated by an XRB and hence the point would appear lower in the plot (that is, at higher  $kT$ ). We suspect that the Group (i) points are mainly SNRs or other emission-line sources: alternatively, these sources may also be XRBs illuminating adjacent clouds of interstellar material in NGC 7793. We note that strong emission line sources are more difficult to interpret correctly using the quantile approach because strong, low-energy line emission (at CCD spectral resolution) can mimic a source with a continuous spectrum and *lower* column density.

### 3.4. Time Variability

To investigate time variability from the discrete X-ray source population of NGC 7793, we examined two approaches: flux differences between our *Chandra* observation and the *ROSAT* PSPC observation of RP99 as well as variability within the *Chandra* observation itself. For the differences in flux between the two observation epochs, we must consider the flux differences between sources detected by both RP99 and the present work, sources detected by RP99 but not detected by the present work, and sources detected by the present work but not by RP99. We adopted a common energy range (0.2-2.4 keV) to make the flux comparisons as well as a common spectral model (that is, an absorbed power law).

We note that we have recovered all of the RP99 sources. We have found only one *Chandra* source that should have been detected by RP99 if it were active during the *ROSAT* PSPC observation, namely CXOU J235806.6–323757 (see Section 3.1). We considered the seven discrete X-ray sources detected both in this paper and by RP99. Table 6 presents estimates for the *ROSAT* and *Chandra* luminosities of these sources using a power law model with a photon index  $\Gamma=1.5$  and a column density of  $N_H=1.15\times10^{20}$  cm $^{-2}$ . For CXOU J235746.7–323607 we also included a luminosity estimate based upon the *Einstein* observation of this source as described by Harris et al. (1994) and designated in that work as 2E 2355.2-3253.

Precise comments for time variability are hampered by the lower quality PSF of *ROSAT* relative to *Chandra*. The broader PSF of *ROSAT* mixed diffuse emission into the discrete emission, raising the overall count rate as well as altering the nature of the spectrum, depending upon the size of the counts aperture used. The presence of the mixing may be noted because all of our *Chandra* luminosity estimates are at least 10% lower than the *ROSAT* values.

Regardless, several sources stand out and merit a brief discussion. CXOU J235806.6-

323757 should have been detected, implying at least an increase in flux by a factor of  $\sim 30$ -50. CXOU 235748.6-323234 decreased by a factor of  $\sim 20$  while CXOU J235800.1-323325 decreased by a factor of  $\sim 6$ -7. We therefore identify a total of three variable discrete X-ray sources in NGC 7793: the remaining sources decreased by modest amounts (factors of  $\sim 2$ ) or are constant within the errors.

To test for variability within the *Chandra* observation, we used the standard *CIAO* tools to first barycenter the data and then extract light curves for each detected point source. The light curves were binned into 60-second intervals and these binned light curves were then run through a Bayesian variability detector (the *CIAO* tool `glvary`). None of the sources exhibited statistically significant variability. An examination of each light curve verified that the light curves of all of the discrete sources were constant within the errors.

### 3.5. Point Source Spatial Asymmetry

We noted above that a majority of the point sources are located in the eastern half of the galaxy and none are located in the northwestern quadrant. Such a peculiar distribution of sources is difficult to reconcile with the general orderly and symmetric optical appearance of the galaxy. Explanations for such a distribution include an excess absorption toward the northwestern quadrant of the galaxy, a random probability in the distribution of the sources, a gravitational interaction between NGC 7793 and another galaxy, dramatically lower effective exposure on this portion of the chip during the observation and “patchy” star formation activity in NGC 7793. We rule out an excess absorption toward the northwest quadrant based on inspection of maps of dust column density toward NGC 7793 as provided by Schlegel et al. (1998). These maps indicate a dust differential measure of only 2% across the face of NGC 7793, which is insufficient to account for the observed asymmetry. We consider the other four explanations here in turn.

We first consider a strictly random interpretation, that is, if most of the sources are X-ray transients, by chance we observed NGC 7793 at an epoch where sources in the northwestern portion of the galaxy were in an off state. Consider, for example, treating NGC 7793 as a dartboard. Noting that approximately one-quarter of the galaxy is devoid of point sources, we can calculate the probability (based on areas) that 20 point sources land outside one quadrant to be  $\sim(3/4)^{20} \approx 3 \times 10^{-3}$ . If we instead consider on-and-off variability and assume that approximately eight sources in one quadrant must be “off”<sup>6</sup>, the probability of not detecting any source at all in this quadrant is  $\sim(1/2)^8 \approx 4 \times 10^{-3}$ . We readily acknowledge the *a posteriori* nature of our argument but we nonetheless consider the orders of magnitude instructive. Having stated our interpretation, the difficulty with this interpretation is the lack of sources in the northwest quadrant in all of the prior *Einstein* and *ROSAT* observations as well as the *Chandra* observation considered here. This result makes an explanation based on short-term time-variability of the discrete X-ray sources less likely.

A gravitational interaction with another member (or multiple galaxies) of the Sculptor Group is another possibility for explaining the asymmetry: such an interaction should also trigger enhanced massive star formation within NGC 7793. The signposts of an elevated star formation rate have been revealed by numerous observations of NGC 7793 including copious amounts of diffuse radio continuum emission and diffuse [S II] emission from the galaxy’s disk (Harnett 1986; Blair & Long 1997), the elevated infrared and blue luminosities of this galaxy for its Hubble type (Read & Pietsch 1999) and the considerable population of resident OB associations and HII regions (Davoust & de Vaucouleurs 1980; Ferguson et al.

---

<sup>6</sup>The estimate of eight sources is based on the fact that because 20 sources are detected in approximately three-quarters of the area of the galaxy, we may thus expect  $(4/3) \times 20 \approx 28$  sources in the whole galaxy.

1996).

We have inspected tabulated information and distribution maps of the Sculptor Group member galaxies as provided by Puche & Carignan (1988) and Karachentsev et al. (2003) to identify a galaxy (or galaxies) which may be interacting with NGC 7793. The galaxy closest to the southeastern edge of NGC 7793 is the Sculptor Diffuse Irregular Galaxy (SDIG, also known as ESO349-G031) (Laustsen et al. 1977; Heisler et al. 1997): the HI mass of the SDIG has been estimated to be  $1.1 \times 10^7 M_{\odot}$  (Cesarsky et al. 1977) which is more than an order of magnitude less than the HI mass of NGC 7793. Assuming a distance of 4.1 Mpc to the SDIG (Karachentsev et al. 2003), the projected separation between this galaxy and NGC 7793 is only 0.3 Mpc. Supporting evidence for a physical association between NGC 7793 and the SDIG is presented by Karachentsev et al. (2003), who argue that the SDIG and a second dwarf galaxy (UA 442) are companions to NGC 7793 based on similar measured radial velocities for all three galaxies. NGC 55, the nearest major Sculptor Group spiral galaxy to NGC 7793, does not appear to be interacting significantly with NGC 7793. While the HI mass of NGC 55 ( $9 \times 10^8 M_{\odot}$ , Puche et al. 1991) more closely matches the HI mass of NGC 7793, the projected distance from NGC 7793 is rather large (2.1 Mpc) if a distance of 1.8 Mpc to NGC 55 is assumed (Karachentsev et al. 2003). In fact, Karachentsev et al. (2003) argue that NGC 55 is instead associated with a third major Sculptor Group spiral galaxy NGC 300. This conclusion was also reached by Pietrzynski et al. (2006), who have separately derived a distance of 1.9 Mpc to NGC 55. We can quantify the likelihood of an interaction between NGC 7793 and either the SDIG or NGC 55 by calculating the tidal index  $\Theta$  (Karachentsev & Makarov 1999), which may be defined as follows. If  $M$  is the mass of the galaxy which is suspected of interacting with a galaxy of interest and  $D$  is the three-dimensional separation between that galaxy and the galaxy of interest, then

$$\Theta = \log(M/D^3) + C, \quad (3)$$



where  $C$  is a constant equal to  $-11.75$  when  $M$  is expressed in units of solar masses and  $D$  is expressed in units of megaparsecs. If  $\Theta$  is calculated to be less than zero, then it may be safely concluded that the galaxy of interest and the suspected interacting galaxy are not in fact interacting to a significant extent. We calculate values for  $\Theta = -3.14$  and  $\Theta = -3.76$  in the cases of NGC 55 interacting with NGC 7793 and the SDIG interacting with NGC 7793, respectively. Based on these strongly negative values for the tidal index in both cases, we conclude that a gravitational interaction is an unlikely explanation for the observed asymmetry. Separately, we have also inspected GALEX data for NGC 7793 to search for any obvious asymmetry in the ultraviolet morphology of the galaxy (as might be expected by lopsided star formation) but we find no evidence for an asymmetric appearance at that wavelength.

Next, we considered the possibility that the effective exposure time of the portion of the ACIS-S3 chip that sampled the northwestern quadrant of NGC 7793 was significantly lower than for the rest of the chip, thereby leading to an observed deficit of discrete X-ray sources in this part of the galaxy. In Figure 11, we present a contour plot showing the effective exposure for the ACIS-S3 chip during the observation: for illustrative purposes, we also include the positions of the detected discrete X-ray sources, the location of the aimpoint for the observation and finally an ellipse that spans the optical extent of the galaxy. We argue that in fact the effective exposure time for this portion of the chip is not significantly lower than for the rest of the chip and that therefore a different effective exposure time cannot account for the observed asymmetry of the detected discrete X-ray sources.

Lastly, regarding the “patchy” star formation scenario, we have also considered the work of Smith et al. (1984), who described how the star formation activity in NGC 7793 is stochastic and occurs only in large irregular “patches”; such “patchy” activity may also

explain the observed asymmetric distribution of sources. Smith et al. (1984) accurately modeled the star formation activity in this galaxy using a stochastic self-propagating star formation model without an imposed spiral modulation. Those authors also commented that “flocculent” galaxies such as NGC 7793 (as described by Elmegreen 1981) in general lack spiral modulation to star formation and feature a “patchy” arm structure. The lack of spiral modulation in NGC 7793 is also supported by the absence of prominent emission from the galaxy’s nucleus at any wavelength. If the star formation in the northwest quadrant happened to belong to one large “patch,” then the lack of X-ray sources not only at the *Chandra* epoch but also at the epochs of the prior X-ray observations can be explained. However, this scenario lacks the full status of an explanation given that we do not have a method to date such a “patch.”

Therefore, at the present time we cannot provide a clear explanation for the observed asymmetry of discrete X-ray sources in NGC 7793. Random probability seems more likely than such explanations such as a gravitational interaction with another galaxy or stochastic star formation but additional study and analysis is required.

#### 4. Diffuse Emission

A spectrum of the diffuse emission was extracted following the method described by Schlegel et al. (2003). Point sources were removed by screening out all events within a radius that enclosed  $>95\%$  of the PSF at the detected position of each point source. The screening radius was increased to match the increase in the PSF with off-axis angle. The resulting holes were filled in by randomly selecting from an annulus surrounding each source the approximate number of events that would have been present based on the count rate

in the annulus.<sup>7</sup> This process assumes only spectral and spatial uniformity of the diffuse emission on spatial scales of  $\sim 20\text{--}30''$ . The inner radius of the annulus used for the back-fill was twice the outer diameter of the source screening radius to reduce the probability that the selected events were point source events scattered by the wings of the PSF. The annulus was  $20''$  wide. Annulus overlaps with other point sources were minimal, but were avoided by sampling events from the non-overlapping portions of the annulus. A radial profile of the diffuse emission was obtained from azimuthal sums in  $10''$ -wide annuli centered on the nucleus. The diffuse spectrum was then extracted using an aperture with a radius of  $\sim 3'.7$  determined by the point at which the diffuse profile joined the local (non-galaxy) background. An estimate of the impact of the backfill may be determined by summing the extraction areas of the point sources and dividing by the extraction area of the entire galaxy. For NGC 7793, those values are  $1900 \text{ arcsec}^2$  and  $1.55 \times 10^5 \text{ arcsec}^2$ , respectively, for an impact ratio of  $\sim 1.2\%$ .

The spectral fit of the diffuse emission spectrum was carried out in two steps. First, the background was fit using a variety of continuum and line features to achieve a good fit as described in Schlegel et al. (2003). Second, the diffuse spectrum + background was fit simultaneously with the background by adopting for the background the best-fit parameters determined in the first step<sup>8</sup>. A version of the optically-thin thermal plasma model APEC (Smith et al. 2001) which is known as “VAPEC” and which includes variable elemental abundances as determined using recent atomic physics was used to

---

<sup>7</sup>We could ignore the regions surrounding point sources but our analysis of the diffuse emission is part of an investigation of the spatial distribution of the diffuse emission in face-on spirals for which we do not want holes (Schlegel et al. 2011, in preparation).

<sup>8</sup>This approach preserves the proper statistical distribution in contrast to a background-subtracted spectrum and has become common practice in the field since Cash (1979).

fit the spectrum. Abundances were allowed to vary but if an abundance was found to have an error that included unity, the abundance value was reset and fixed at unity. The known absorbing column density toward NGC 7793 was adopted and the corresponding fit parameter was fixed at that value. The background spectrum contained a large fluorescent Si feature at  $\sim 1.78$  keV. The background fit easily matched the data, but the result slightly over-corrected the source spectrum because of photon statistics. We excised the data at this location: this excision has a negligible effect on the fit as the dominant emission from the hot gas occurs in the 0.5-1 keV band. We also included a power law component to account for any hard emission present from unresolved point sources. The results of our fits are summarized in Table 7.

In Figure 12 we present the extracted spectrum of the diffuse emission as fit with the VAPEC model. The fitted temperature of the diffuse spectrum of NGC 7793 was found to be  $kT = 0.19^{+0.03}_{-0.02}$  keV and  $N_{\text{H}} = 3.6 \times 10^{21} \text{ cm}^{-2}$ ,  $kT = 0.22 \pm 0.02$  keV for the dual APEC fit, or  $kT = 0.25 \pm 0.02$  keV if  $N_{\text{H}}$  is fixed at the Galactic column density. These values are lower than the temperatures derived by RP99 (namely  $kT \sim 0.8$ -1.1 keV) using typical thermal models such as thermal bremsstrahlung and the Raymond-Smith thermal plasma. The most likely explanation for the discrepancies in the fitted temperature is the mixing of the diffuse emission with point source emission from the broad wings of the *ROSAT* PSPC PSF. For the PSPC, a circle enclosing 90% of the flux was  $0.9'$  in diameter at 1 keV but  $2.7'$  in diameter at 1.7 keV. RP99 adopted an aperture of  $1'$  so sources with harder spectra and hence larger PSFs would preferentially contribute flux above a PSF radius of  $\sim 1.1'$ . In addition, weak unresolved point sources would blend to form a brighter “diffuse” component.

The fitted temperature of the diffuse emission is similar to the results from fits to the diffuse components of other nearby galaxies: in Table 8 we list several values measured

for the diffuse emission from other galaxies for comparison. NGC 7793 stands out for the absence of a second, hotter diffuse component. We attempted to fit a second APEC model (i.e., VAPEC + VAPEC + Power Law), but the model normalization of the second APEC component was consistent with zero. A second APEC component was non-zero only if the  $N_{\text{H}}$  was fixed at the known Galactic column. We expect that a longer exposure would lead to sufficient statistics to separate a hot component from the background emission without the necessity of additional model constraints. The abundance of each element was permitted to vary, but only the abundance of Ne in the fixed  $N_{\text{H}}$  VAPEC model was significantly different from 1.0: in this case, the best-fit value for the abundance was  $2.23^{+0.74}_{-0.66}$ . In Figure 13 we present confidence contour plots for the column density and the fitted temperature for the APEC fit (left) as well as the fitted temperature and neon abundance for the VAPEC fit in which the column density was fixed at the known Galactic value (right).

We also modeled the spectrum as a sum of unresolved Gaussians plus a power law with emission Gaussians at 0.60, 0.75, and 0.89 keV, corresponding approximately to emission lines attributed to O VII, Fe L shell, and Ne IX. The presence of these lines is expected in hot diffuse gas. The model fits (with both  $N_{\text{H}}$  free and fixed) were consistent with the APEC+Power Law model, but applying Occam’s razor, this model is penalized by the extra components and constraints necessary to obtain a good fit. While the multi-Gaussian fit implies the presence of specific emission lines, the VAPEC model provides the statistically acceptable fit and we consider it the best-fit model.

For the adopted Galactic column density and the VAPEC model, we calculate absorbed and unabsorbed fluxes for the diffuse emission of  $\sim 5.4 \times 10^{-13}$  and  $\sim 5.5 \times 10^{-13}$  erg s $^{-1}$  cm $^{-2}$ , respectively, in the 0.5-2 keV band. For the assumed distance to NGC 7793, the unabsorbed flux corresponds to a luminosity of  $L_X \sim 3.3 \times 10^{38}$  erg s $^{-1}$ .

## 5. Luminosity Function of Discrete X-ray Sources

A plot of  $N$  (defined as the number of sources with luminosities in excess of the luminosity  $L_X$ ) versus  $\log L_X$  for the NGC 7793 discrete sources (with luminosity units of  $10^{38}$  erg s $^{-1}$ ) is shown in Figure 14. Several functions are plotted, including the complete luminosity function for NGC 7793, the luminosity function without the two known foreground stars, and the function without the ULX and the two foreground stars. For comparison, the luminosity function of NGC 2403 (Schlegel & Pannuti 2003) and a line of slope  $\Gamma = -0.65$  are also shown. The excluded ULX is very bright and its inclusion leads to a long tail in the distribution, potentially requiring a two-component fit. We discuss the complete and the ULX-less functions solely for comparison with the luminosity functions of other galaxies.

A linear fit to the complete function ( $\log N$  versus  $\log L_X$ ) yields a slope of  $\Gamma \sim -0.62 \pm 0.2$ , but the residuals are large ( $\chi^2/\nu \sim 1.24$ ). For the ULX-less luminosities, the linear slope has an absolute value of  $\Gamma = -0.65 \pm 0.11$  ( $\chi^2/\nu \sim 1.03$ ). Both values are comparable to the  $\log N$ - $\log S$  slopes for NGC 6946 ( $\Gamma \sim -0.64$ ; Holt et al. (2003)) or NGC 2403 ( $\Gamma \sim -0.59$ ; Schlegel & Pannuti (2003)) but are dissimilar to the slopes of IC 5332 or M83 ( $\Gamma = -1.30 \pm 0.31$  and  $\Gamma = -1.38 \pm 0.28$ , respectively; Kilgard et al. (2002)).

Note that the slope of  $\Gamma = -0.65$  is well-defined in the narrow luminosity range of  $\sim 37.1 < \log L_X < \sim 37.8$  in contrast to the slope of NGC 2403 (determined over the range  $\sim 36.3 < \log L_X < \sim 39.0$  – see Schlegel & Pannuti (2003)). There are a deficit of sources in NGC 7793 at low ( $< 37.0$ ) and high ( $\sim 38.3$ – $39.0$ )  $\log L_X$ . Both galaxies occupied a similar area on the ACIS CCDs, so any loss of sources at low  $L_X$  does not provide an explanation. If one or two luminous LMXBs were off during the observation epoch, the deficit at  $\log L_X \sim 38.3$  to  $\sim 39.0$  is readily explained. At the present time, we have information on the time variability of only the most luminous sources (see Section 3.4).

In previous work, differences between the slopes of the luminosity functions of the different galaxies may be reconciled by applying corrections for star formation rates. This result was demonstrated by Grimm et al. (2002) who aligned seemingly discrepant luminosity functions after applying corrections for star formation rates in these galaxies. In the case of NGC 7793, such a correction is small (Storchi-Bergmann et al. 1994). In Table 9, we present estimates of both  $\Gamma$  and star formation rates (in units of  $M_{\odot} \text{ yr}^{-1}$ ) for five galaxies, including NGC 7793. In contrast to the work of Grimm et al. (2002), we find no obvious correlation between the values of the slopes and the star formation rates of the five galaxies we list in Table 9.

## 6. The Multi-Wavelength Properties of the SNR Population of NGC 7793

Lastly we comment on the multi-wavelength properties of the SNR population of NGC 7793. As noted previously, prior to the present work a total of 32 SNRs had been identified in this galaxy by previous surveys conducted at X-ray, optical and radio wavelengths (Blair & Long 1997; Read & Pietsch 1999; Pannuti et al. 2002). In Section 3, we presented a spectral analysis of CXOU J235746.7–323607, the X-ray counterpart to the candidate radio SNR R3 that was identified by Pannuti et al. (2002) and concluded that the X-ray source was time-variable. We also exclude this source from our discussion here of the multi-wavelength properties of the SNR population of NGC 7793, reducing the size of the sample of sources to 31.

By virtue of its superior angular resolution, *Chandra* potentially yields a significant improvement over *ROSAT* (which imaged NGC 7793 previously) in studies of the SNR population of an external galaxy. To identify X-ray counterparts to these known SNRs, we have cross-correlated the list of discrete X-ray sources detected in this galaxy (see Table 2) with the positions of the known SNRs (as described in Section 3.2). We have clearly

detected only one additional SNR, the optically-identified SNR N7793-S11, which has also been detected in the radio by Pannuti et al. (2002). To investigate the scenario where the X-ray counterparts to the SNRs may be extended and faint which could be missed by **wavdetect**, we extracted counts at the locations of all of the 30 remaining SNRs. For the optically-identified SNRs we used apertures that corresponded to the sizes of the angular extents of these SNRs (ranging in size from  $\sim 2''$  to  $\sim 10''$  in radius) while for the candidate radio SNRs we used apertures that were  $3''$  in radius. We did not detect any additional SNRs to a limiting count rate of  $\sim 1 \times 10^{-4}$  cts s $^{-1}$ : we note that this search is further confused by diffuse X-ray emission from the disk of NGC 7793 as well. To estimate a corresponding limiting luminosity for this count rate, we consider the work of Long et al. (2010) who conducted an X-ray survey of the SNR population of the nearby face-on spiral galaxy M33 with *Chandra*, known as the *Chandra* ACIS Survey of M33 (ChASeM33 – see Plucinsky et al. (2008)). Those authors assumed a soft thermal ( $kT = 0.6$  keV) spectrum with a sub-solar metal abundance of 0.5 for calculating the luminosities of detected X-ray counterparts over the energy range of 0.35 - 2.0 keV. Assuming the same model, considering the same energy range and adopting the nominal Galactic column density toward NGC 7793 of  $N_H = 1.15 \times 10^{20}$  cm $^{-2}$ , we calculate a limiting luminosity for our search of  $L_X \sim 7.6 \times 10^{35}$  ergs s $^{-1}$ . The survey conducted by Long et al. (2010) identified 7 (out of 131 SNRs observed by the survey) with X-ray luminosities in excess of this limit for a detection rate of 5%: this value closely matches our detection rate of one SNR detected (out of 31 SNRs observed) of 3%.

We find therefore that we can reconcile the detection rate of X-ray counterparts to SNRs in NGC 7793 with the detection rate of X-ray counterparts to SNRs in M33 as presented by Long et al. (2010). For comparison purposes, we note that over ten Galactic SNRs are known to have unabsorbed X-ray luminosities that exceed the limiting luminosity



attained by our *Chandra* observation:<sup>9</sup> it is possible that the discrepancy between NGC 7793 and the Milky Way may be simply due to the lower mass and star formation rate of NGC 7793 compared to the Milky Way. Figure 15 presents a Venn diagram summarizing the overlap of detections of the 31 SNRs identified at multiple wavelengths in NGC 7793 as updated with the results of the present work.

Pannuti et al. (2007) presents and discusses wavelength-dependent selection effects in our search for SNRs in a sample of nearby galaxies using *Chandra* observations. Long et al. (2010) also discuss multi-wavelength properties of the sample of known SNRs in M33: those authors describe the importance of local gas density in dictating the X-ray properties of SNRs as well as consider how optical morphology and environment of the SNR may affect its detectability in the X-ray. The reader is referred to both of these works for a more complete discussion of multi-wavelength properties of SNRs. We note that the detection of X-ray emission from N7793-S11 is significant in that this source is one of only a very few extragalactic SNRs located beyond the Local Group which have been detected in the X-ray, optical and radio bands.

## 7. Conclusions

The conclusions of this paper may be summarized as follows:

- 1) We detected 22 discrete X-ray sources within the optical extent of NGC 7793 in a 49094 sec exposure. The sources are significant at the  $\sim 3\sigma$  level or greater and correspond to a limiting unabsorbed luminosity of  $\sim 3 \times 10^{36}$  ergs s<sup>-1</sup> over the 0.2-10.0 keV energy range.
- 2) Four sources had a sufficient number of counts to allow spectral fitting. Acceptable

---

<sup>9</sup>See “The *Chandra* Supernova Remnant Catalog” (<http://hea-www.harvard.edu/ChandraSNR>).

fits were derived using either a power law, a bremsstrahlung model, an APEC model or a disk blackbody model plus zero-width Gaussians to simulate unresolved lines. Column densities were generally higher than the known Galactic value toward NGC 7793 – in fact, fits using the known Galactic value were generally poor. Our derived fit to the extracted spectrum of the ULX using the DiskBB model returns a value for  $kT_{in}$  of approximately 2.0 keV, consistent with the interpretation provided by RP99 that this source is an XRB featuring a  $\sim 10 M_{\odot}$  mass black hole. All sources were investigated using a quantile color-color plot. Time variability was investigated through comparisons of the fluxes between our *Chandra* data and the RP99 results. Three sources were shown to have varied by factors of  $\sim 6$  to 30 or more.

3) We searched for counterparts at multiple wavelengths for the detected X-ray sources. Based on our search, we have identified counterparts to one SNR, one HII region and two foreground stars; the remaining sources are likely to be XRBs and luminous X-ray SNRs native to NGC 7793 and background galaxies seen through the disk of the galaxy. The detected SNR – N7793-S11 – is also detected in the optical and radio, making it one of the few SNRs located outside of the Local Group to be detected at all three wavelengths. We have also ruled out the possibility that the candidate radio SNR R3 is a single SNR.

4) A remarkable asymmetry is seen in the distribution of X-ray sources in this galaxy, with the large majority seen in the eastern half. Possible explanations for this asymmetry include a gravitational interaction with a nearby galaxy or stochastic star formation.

5) The fitted temperature of the diffuse emission is  $kT=0.253^{+0.018}_{-0.015}$  keV, lower than the temperature measured by RP99. The discrepancy can be explained by the significant mixing of the diffuse emission with point source emission from the broad wings of the *ROSAT* PSPC PSF.

6) We constructed the luminosity function for the detected discrete X-ray sources in

NGC 7793. If the known ULX in this galaxy is excluded, the absolute value of the fitted slope is  $\Gamma = -0.65 \pm 0.11$ , but the shape is linear over a small range. If the ULX is included, the absolute value of the fitted slope becomes  $\Gamma = -0.62 \pm 0.2$  but the residuals of the fit are much larger.

We thank the referee for many helpful comments that have significantly improved the quality of this paper. We thank A.M.N. Ferguson for kindly sharing her  $H\alpha$  and R-band images of NGC 7793 for the purposes of this research. T.G.P. acknowledges useful discussions with Nebojsa Duric about properties of SNRs and Phil N. Appleton about the peculiar distribution of the discrete X-ray sources in NGC 7793. T.G.P. also thanks Lauren Jones for reviewing this manuscript and commenting on the phenomenon of star formation in galaxies. This research has made use of NASA’s Astrophysics Data System as well as the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. This research has also made use of data obtained from the High Energy Astrophysics Science Archive Research Center (HEASARC), provided by NASA’s Goddard Space Flight Center. This work is supported by Chandra Grant GO3-4104Z and this research has made use of software provided by the *Chandra X-ray Center (CXC)* in the application package *CIAO*.

Facilities: CXO(ACIS).

## REFERENCES

- Arnaud, K. A. 1996, *Astronomical Data Analysis Software and Systems V*, eds. Jacoby G. and Barnes J., p. 17, *Astronomical Society of the Pacific Conference Series Volume 101*
- Blair, W. P. & Long, K. S. 1997, *ApJS*, 108, 261
- Bowen, D. V., Osmer, S. J., Blades, J. C., Tytler, D., Cottrell, L., Fan, X.-M. & Lanzetta, K. M. 1994, *AJ*, 107, 461
- Campana, S., Moretti, A., Lazzati, D. & Tagliaferri, G. 2001, *ApJ*, 560, L19
- Carignan, C. 1985, *ApJS*, 58, 107
- Carignan, C. & Puche, D. 1990, *AJ*, 100, 394
- Cash, W. 1979, *ApJ*, 228, 939
- Cesarsky, D. A., Falgarone, E. G. & Lequeux, J. 1977, *A&A*, 59, L5
- Church, M. J. & Balucinska-Church, M. 2001, *A&A*, 369, 915
- Davoust, E. & de Vaucouleurs, G. 1980, *ApJ*, 242, 30
- Doane, N. E., Sanders, W. T., Wilcots, E. M., & Juda, M., 2004, *AJ*, 128, 2712
- Dopita, M. A. et al. 2010, *ApJ*, 710, 964
- Elmegreen, D. M. 1981, *ApJS*, 47, 229
- Fabbiano, G., Kim, D.-W. & Trinchieri, G. 1992, *ApJS*, 80, 531
- Ferguson, A. M. N., Wyse, R. F. G., Gallagher, III, J. S. & Hunter, D. A. 1996, *AJ*, 111, 2265

- Filipović, M. D., et al. 2008, A&A, 485, 63
- Fraternali, F., Cappi, M., Sancisi, R., & Osterloo, T. 2002, ApJ, 578, 109
- Freeman, P. E., Kashyap, V., Rosner, R. & Lamb, D. Q. 2002, ApJS, 138, 185
- Fruscione, A. et al. 2006, Proc. SPIE, 6270, 60
- Garmire, G. P., Bautz, M. W., Ford, P. G., Nousek, J. A., & Ricker, G. R., Jr. 2003, SPIE, 4851, 28
- Grimm, H.-J., Gilfanov, M. & Sunyaev, R. 2002, A&A, 391, 923
- Harnett, J. I. 1986, PASA, 6, 325
- Harris, D. E., Forman, W., Gioia, I. M., Hale, J. A., Harnden, Jr., F. R., Jones, C., Karakashian, T., Maccacaro, T., McSweeney, J. D., Primini, F. A., et al. 1994, “EINSTEIN2E – *Einstein* Observatory 2E Catalog of IPC X-ray Sources,” SAO HEAD CD-ROM Series I (Einstein), Nos 18-36.
- Heisler, C.A., Hill, T. L., McCall, M. L. & Hunstead, R. W. 1997, MNRAS, 285, 374
- Hodge, P. W. 1969, ApJS, 18, 73
- Holt, S. S., Schlegel, E. M., Hwang, U. & Petre, R. 2003, ApJ, 588, 792
- Hong, J., Schlegel, E. M. & Grindlay, J. E., 2004, ApJ, 614, 508
- Immler, S., Wang, Q. D., Leonard, D. C. & Schlegel, E. M. 2003, ApJ, 595, 727
- Karachentsev, I. D. & Makarov, D. I. 1999, “Galaxy Interactions at Low and High Redshift,” Proceedings of IAU Symposium #186, held in Kyoto, Japan, 26-30 August 1997, Edited by J. E. Barnes and D. B. Sanders, 1999, p. 109 (Dordrecht: Kluwer)

- Karachentsev, I. D., Grebel, E. K., Sharina, M. E., Dolphin, A. E., Geisler, D.,  
Guhathakurta, P., Hodge, P. W., Karachentseva, V. E., Sarajedini, A., & Seltzer, P.  
2003, *A&A*, 404, 93
- Karzas, W. J. & Latter, R. 1961, *ApJS*, 6, 167
- Kellogg, E., Baldwin, J. R. & Koch, D. 1975, *ApJ*, 199, 299
- Kennicutt, R. C., Jr., 1983, *ApJ*, 272, 54
- Kilgard, R. E., Kaaret, P., Krauss, M. I., Prestwich, A. H., Raley, M. T. & Zezas, A. 2002,  
*ApJ*, 573, 138
- Lacey, C. K. & Duric, N. 2001, *ApJ*, 560, 719
- Larsen, S. S. 1999, *A&AS*, 139, 393
- Larsen, S. S. & Richtler, T. 1999, *A&A*, 345, 59
- Laustsen, S., Richter, W., van der Lans, J., West, R. M. & Wilson, R. N. 1977, *A&A*, 54,  
639
- Long, K. S., et al. 2010, *ApJS*, 187, 495
- Makashima, K., Maejima, Y., Mitsuda, K., Bradt, H. V., Remillard, R. A., Tuohy, I. R.,  
Hoshi, R. & Nakagawa, M. 1986, *ApJ*, 308, 635
- Margon, B., Downes, R. A. and Chanan, G. A. 1985, *ApJS*, 59, 23
- Meurer, G. R. et al. 2006, *ApJS*, 165, 307
- Mitsuda, K, Inoue, H., Koyama, K., Makishima, K., Matsuoka, M., Ogawara, Y., Suzuki,  
K., Tanaka, Y., Shibazaki, N. & Hirano, T. 1984, *PASJ*, 36, 741

- Monet, D. G., Levine, S. E., Canizan, B., Ables, H. D., Bird, A. R., Dahn, C. C., Guetter, H. H., Harris, H. C., Henden, A. A., Leggett, S. K. et al. 2003, AJ, 125, 984
- Morrison, R. & McCammon, D. 1983, ApJ, 270, 119
- Motch, C., Pakull, M. W., Grisé, F. and Soria, R. 2011, AN, 332, 367
- Mukai, K., Pence, W. D., Snowden, S. L. & Kuntz, K. D. 2003, ApJ, 582, 184
- Pakull, M. W., Soria, R. & Motch, C. 2010, Nature, 466, 209
- Pannuti, T. G., Duric, N., Lacey, C. K., Goss, W. M., Hoopes, C. G., Walterbos, R. A. M. & Magnor, M. A. 2000, ApJ, 544, 780
- Pannuti, T. G., Duric, N., Lacey, C. K., Ferguson, A. M. N., Magnor, M. A. & Mendelowitz, C. 2002, ApJ, 565, 966
- Pannuti, T. G., Schlegel, E. M. & Lacey, C. K., 2007, AJ, 133, 1361
- Pence, W. D., Snowden, S. L., Mukai, K. & Kuntz, K. D. 2001, ApJ, 561, 189
- Pietrzyński, G., Gieren, W., Soszyński, I., Udalskim A., Bresolin, F., Kudritzki, R.-P., Mennicken, R., Walker, A., Garcia, A., Szewczyk, O., et al. 2006, AJ, 132, 2556
- Plucinsky, P. P., Williams, B., Long, K. S., Gaetz, T. J. et al. 2008, ApJS, 174, 366
- Puche, D. & Carignan, C. 1988, AJ, 95, 1025
- Puche, D., Carignan, C. & Wainscoat, R. J. 1991, AJ, 101, 447
- Read, A. M. & Pietsch, W. 1999, A&A, 341, 8 (RP99)
- Safi-Harb, S. & Petre, R. 1999, ApJ, 512, 784
- Sauty, S., Gerin, M. & Casoli, F. 1998, A&A, 339, 19

- Schlegel, D. J., Finkbeiner, D. P. & Davis, M. 1998, *ApJ*, 500, 525
- Schlegel, E. M. & Pannuti, T. G. 2003, *AJ*, 125, 3025
- Schlegel, E. M., Holt, S. S., & Petre, R. 2003, *ApJ*, 598, 982
- Sivan, J.-P., Maucherat, A. J., Petit, H. & Comte, G. 1990, *A&A*, 237, 23
- Smith, G., Elmegreen, B. G. & Elmegreen, D. M. 1984, *MNRAS*, 210, 399
- Smith, R. K., Brickhouse, N. S., Liedahl, D. A. & Raymond, J. C., 2001, *ApJ*, 556, L91
- Soria, R. & Wu, K. 2003, *A&A*, 410, 53
- Soria, R., Pakull, M. W., Broderick, J. W., Corbel, S. & Motch, C. 2010, *MNRAS*, 409, 541
- Storchi-Bergmann, T., Calzetti, D. & Kinney, A. L. 1994, *ApJ*, 429, 572
- Swartz, D. A., Ghosh, K. K., McCollough, M. L., Pannuti, T. G., Tennant, A. F. & Wu, K. 2003, *ApJS*, 144, 213
- Terashima, Y. & Wilson, A. S. 2001, *ApJ*, 560, 139
- Terashima, Y. & Wilson, A. S. 2004, *ApJ*, 601, 735
- Townsley, L., Broos, P., Garmire, G. P., & Nousek, J. A. 2000, *ApJ*, 534, L139
- Tuellmann, R., 2011, *ApJS*, 193, 31
- Tully, R. B. 1988, *Nearby Galaxies Catalog* (Cambridge: Cambridge University Press)
- Weisskopf, M. C., Brinkman, B., Canizares, C., Garmire, G., Murray, S. & van Speybroeck, L. P. 2002, *PASP*, 114, 1



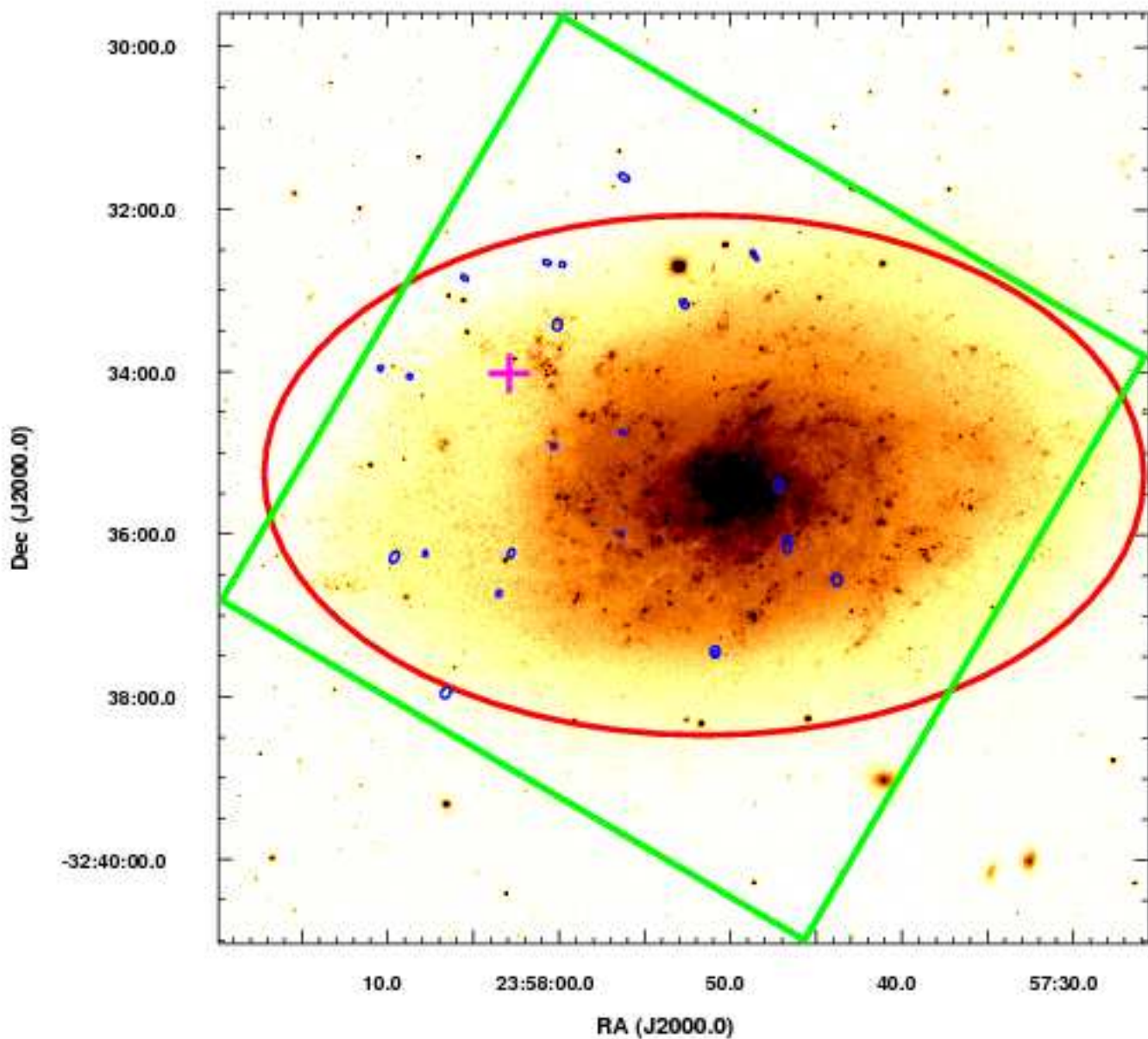


Fig. 1.— R-band image of NGC 7793 with the positions of the detected sources (corresponding to 90% confidence levels) indicated with blue ellipses. The green box indicates the field of view of the ACIS-S3 chip during the observation, the red ellipse indicates the optical extent of NGC 7793 and the magenta cross indicates the aimpoint of the observation. The sizes of the source location ellipses are related to the errors in the determination of the source positions. Notice the asymmetric distribution in the positions of the sources. See Section 3 for a discussion about the discrete sources and Section 3.5 for a discussion about the asymmetric distribution.

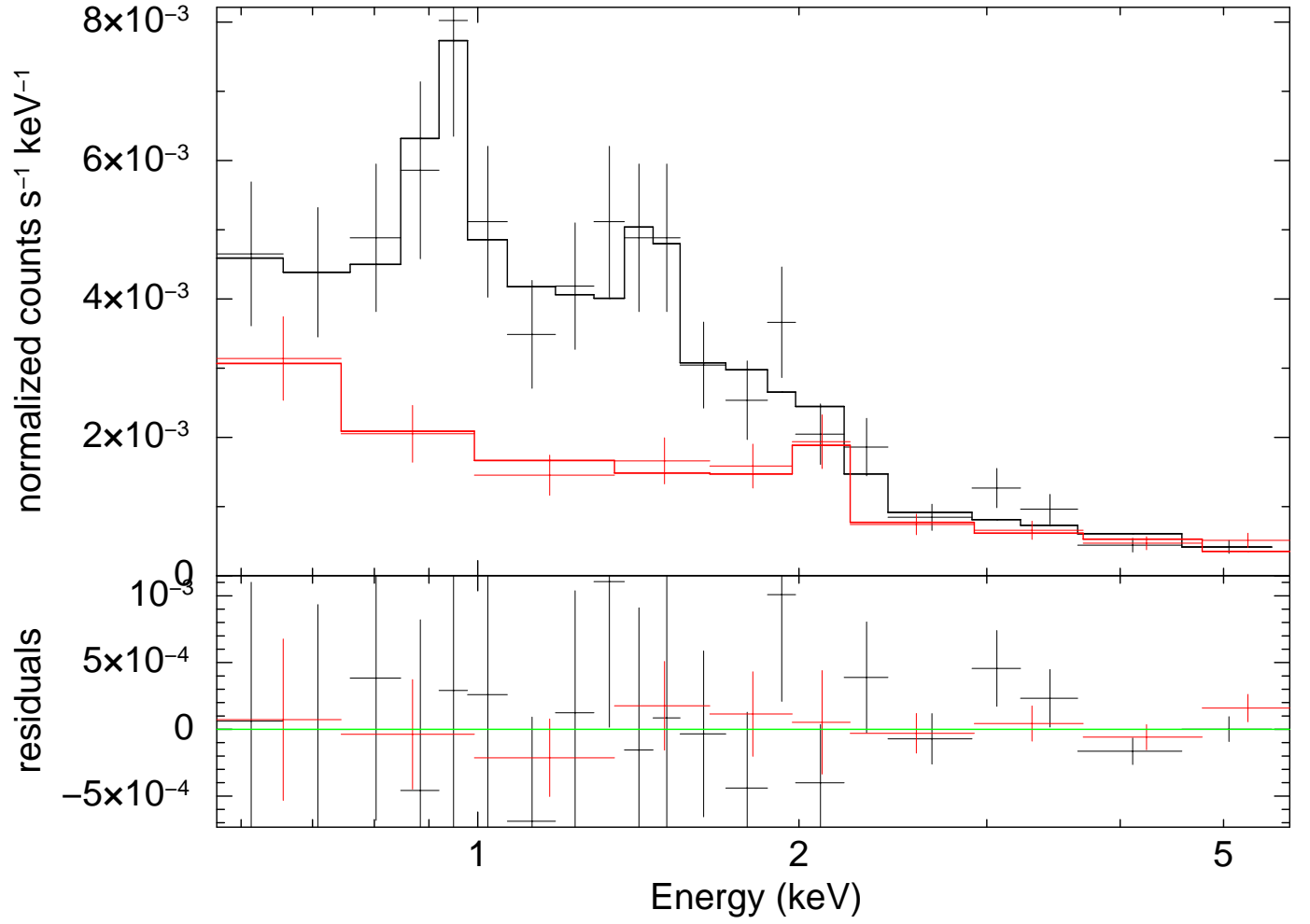


Fig. 2.— Extracted spectrum of CXOU J235746.7–323607 as fit with a power law model (column density thawed). The source spectrum is shown in black while the background spectrum is shown in red.

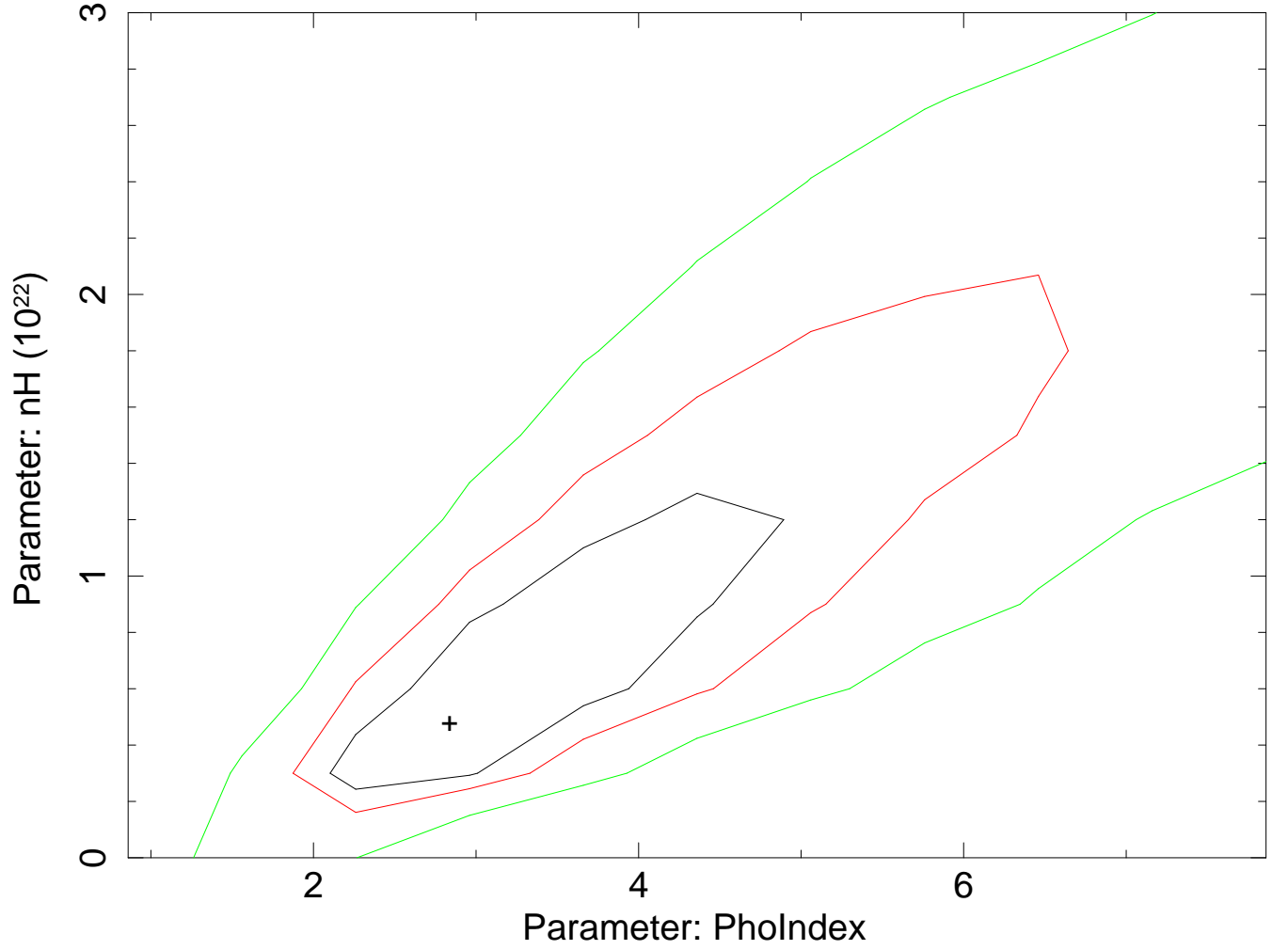


Fig. 3.— Confidence contours for fit (as shown in Figure 2) to extracted spectrum of CXOU J235746.7–323607. The contours are at the  $1\sigma$ ,  $2\sigma$  and  $3\sigma$  levels.

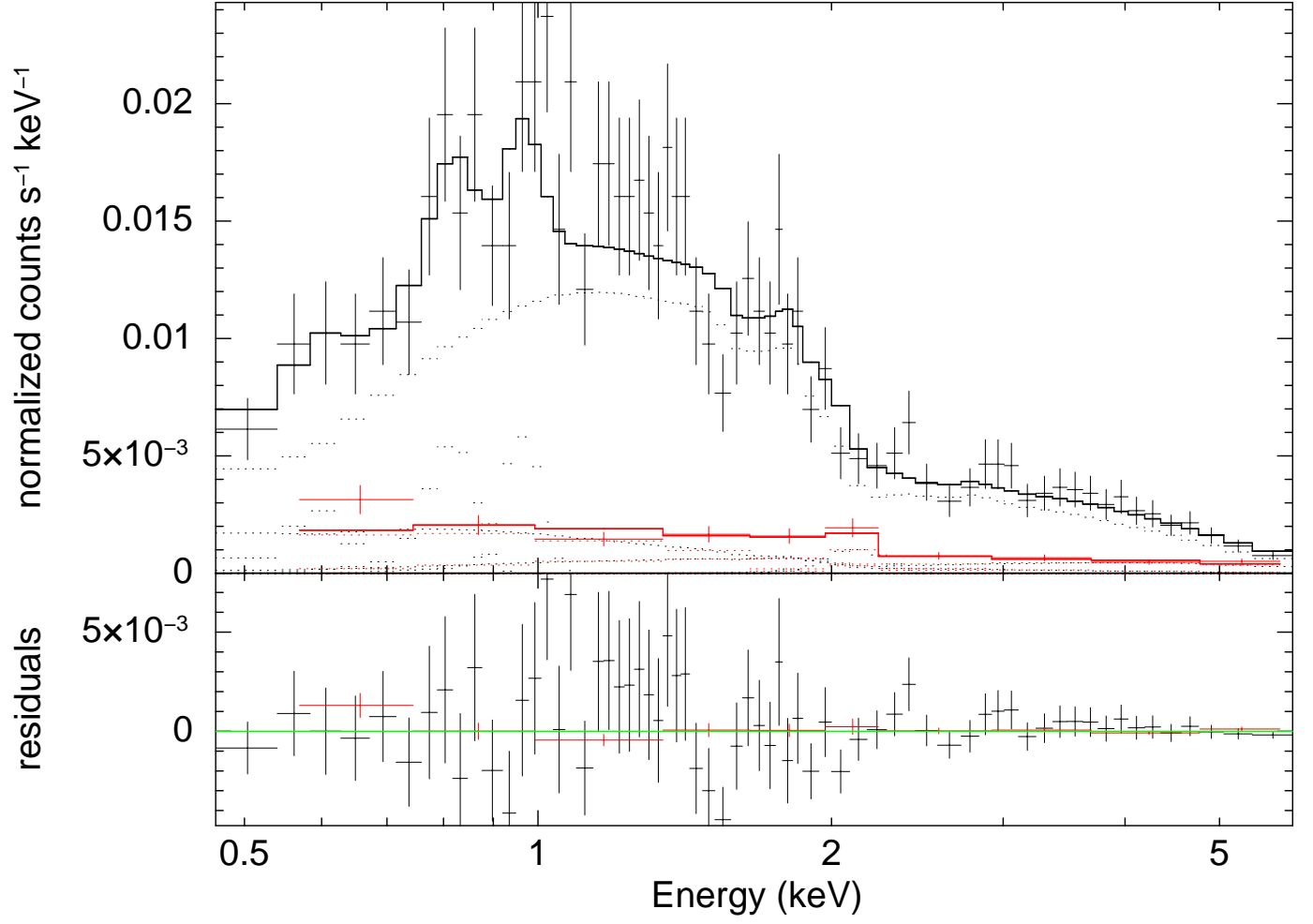


Fig. 4.— Extracted spectrum of CXOU J235750.9–323726 as fit with the DiskBB model (column density thawed). The source spectrum is shown in black while the background spectrum is shown in red. Dashed lines show contributions of the different model components.

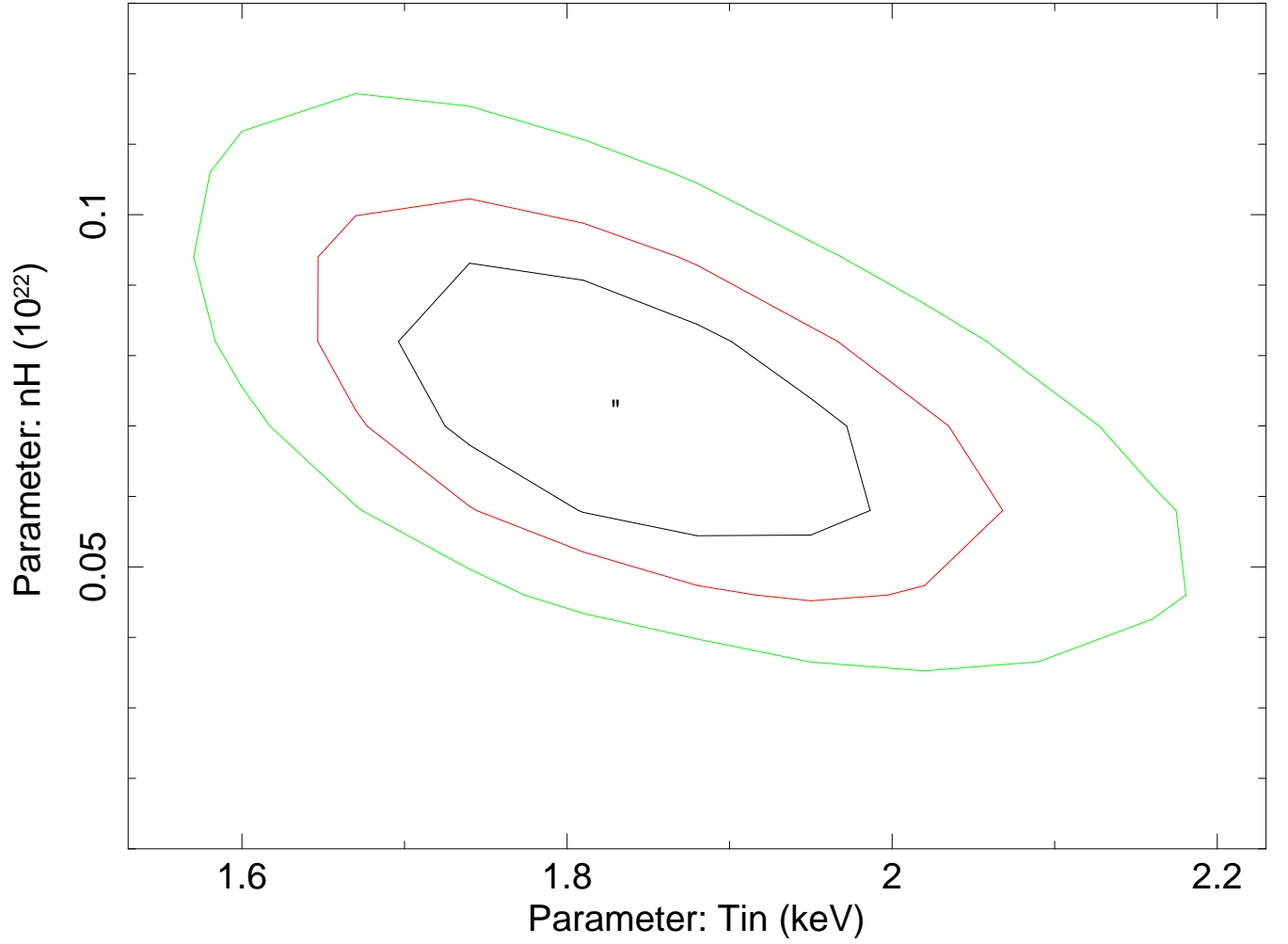


Fig. 5.— Confidence contours for fit (as shown in Figure 4) to extracted spectrum of CXOU J235750.9–323726. The contours are plotted at the same levels as in Figure 3.

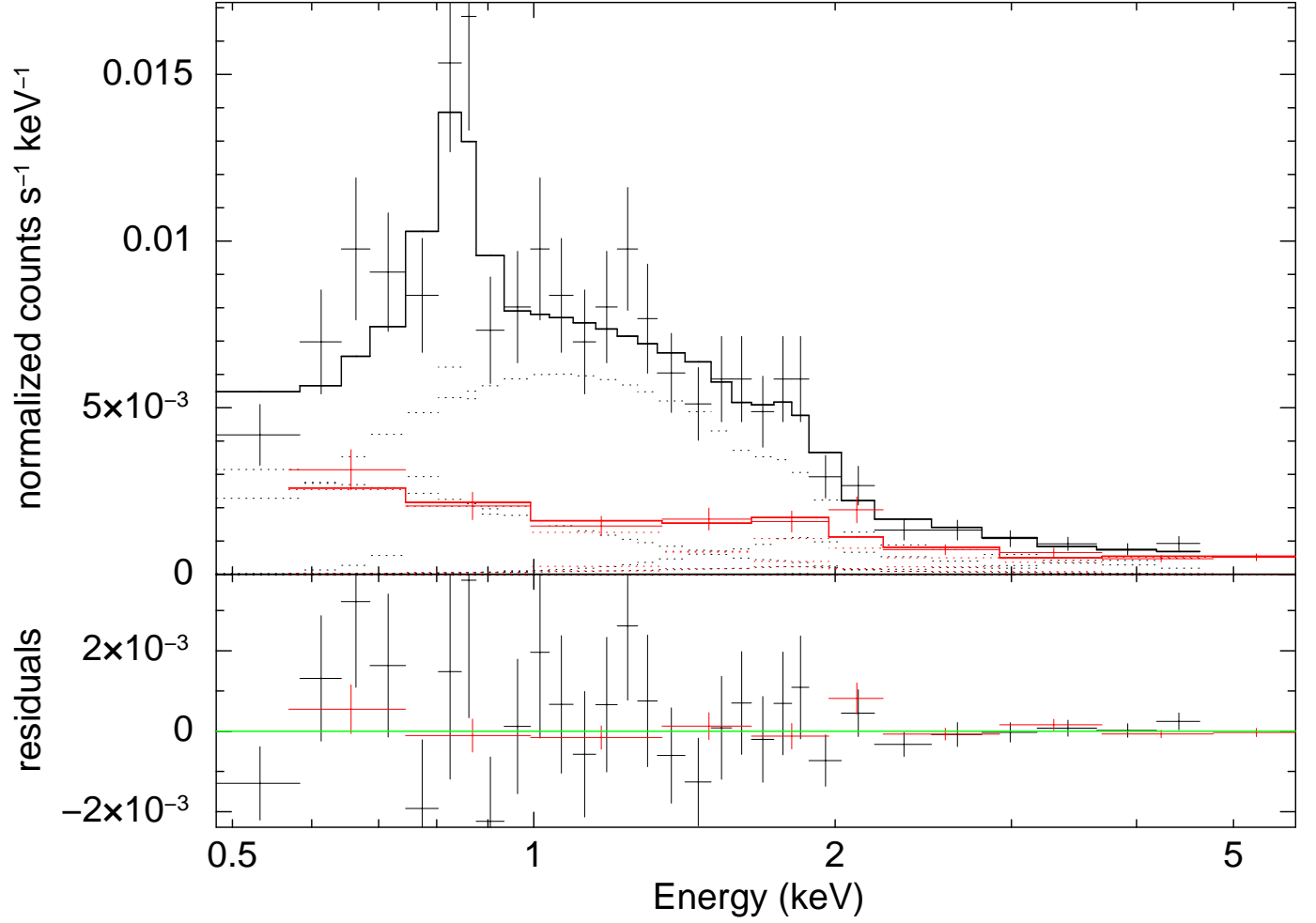


Fig. 6.— Extracted spectrum of CXOU J235806.6–323757 as fit with a power law model. The source spectrum is shown in black while the background spectrum is shown in red. Dashed lines show contributions of the different model components.

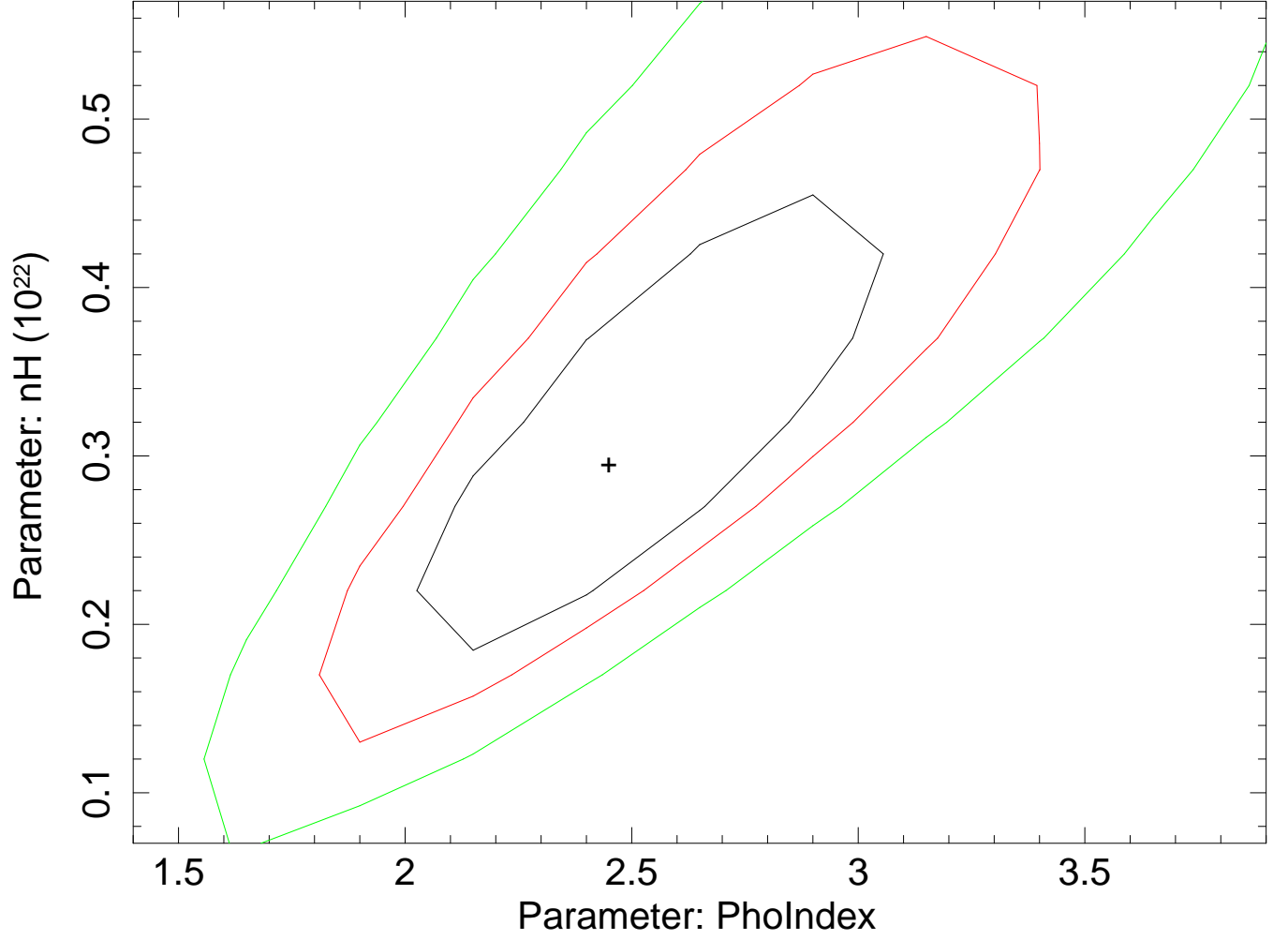


Fig. 7.— Confidence contours for fit (as shown in Figure 6) to extracted spectrum of CXOU J235806.6–323757. The contours are plotted at the same levels as in Figure 3.

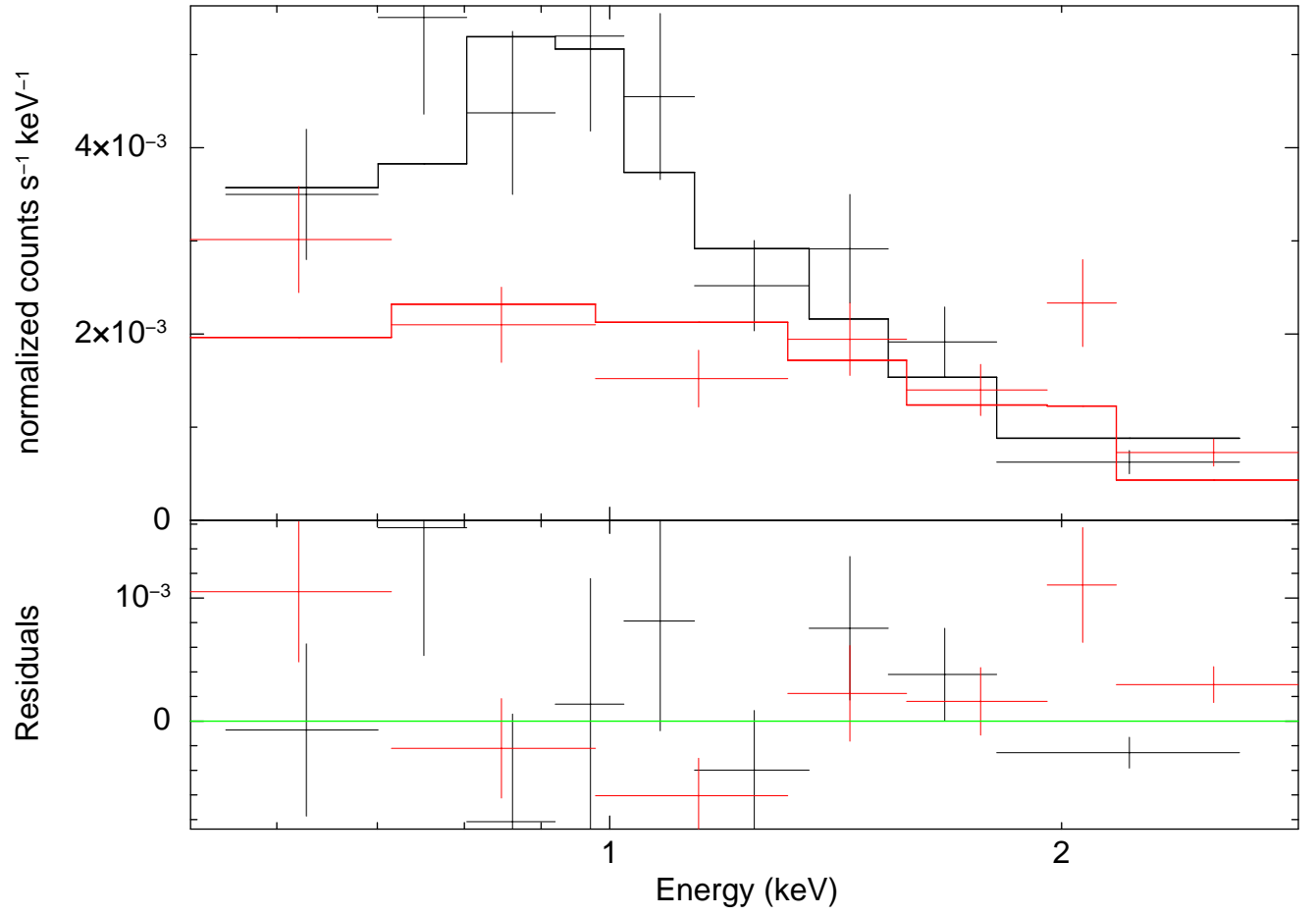


Fig. 8.— Extracted spectrum of CXOU J235808.7–323403 as fit with the APEC model. The source spectrum is shown in black while the background spectrum is shown in red.



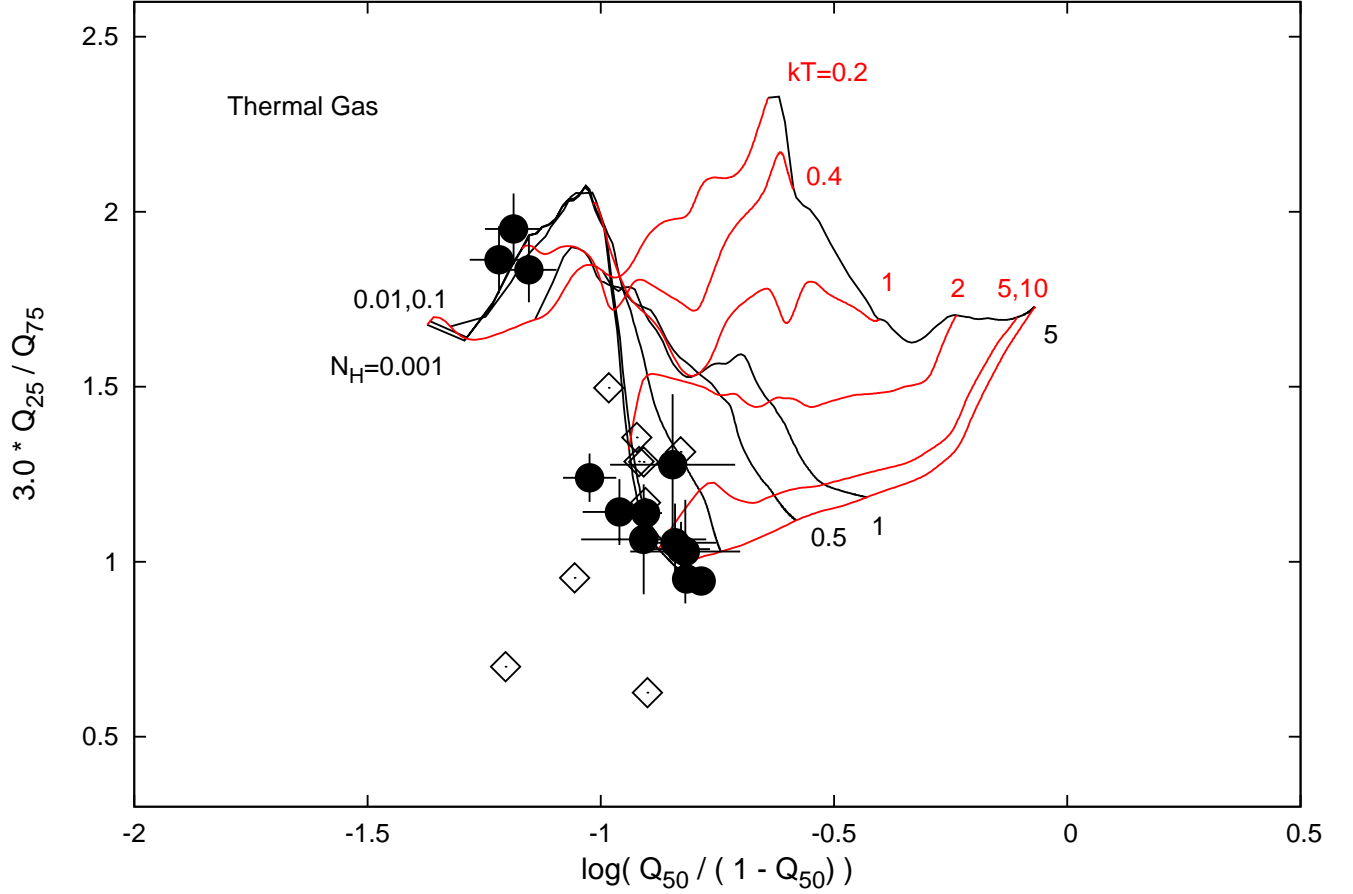


Fig. 9.— Quantile plot for the detected sources in NGC 7793 using an optically-thin gas (APEC) model. Note the two groups of points: a scatter of points at  $3*Q_{25}/Q_{75} \sim 1.25$  and three points at values of  $3*Q_{25}/Q_{75} \sim 2$ . The sources plotted with filled circles exhibit  $1\sigma$  error bars. The sources plotted with open diamonds are weak sources and the resulting errors are large, reducing the legibility of the grid. Error bars are suppressed when the length of the bar covers at least one-half of the grid width. The units for  $N_H$  are  $10^{22} \text{ cm}^{-2}$  and for  $kT$  are keV. See Section 3.3 for a description of the model, the groupings of the points and further details.

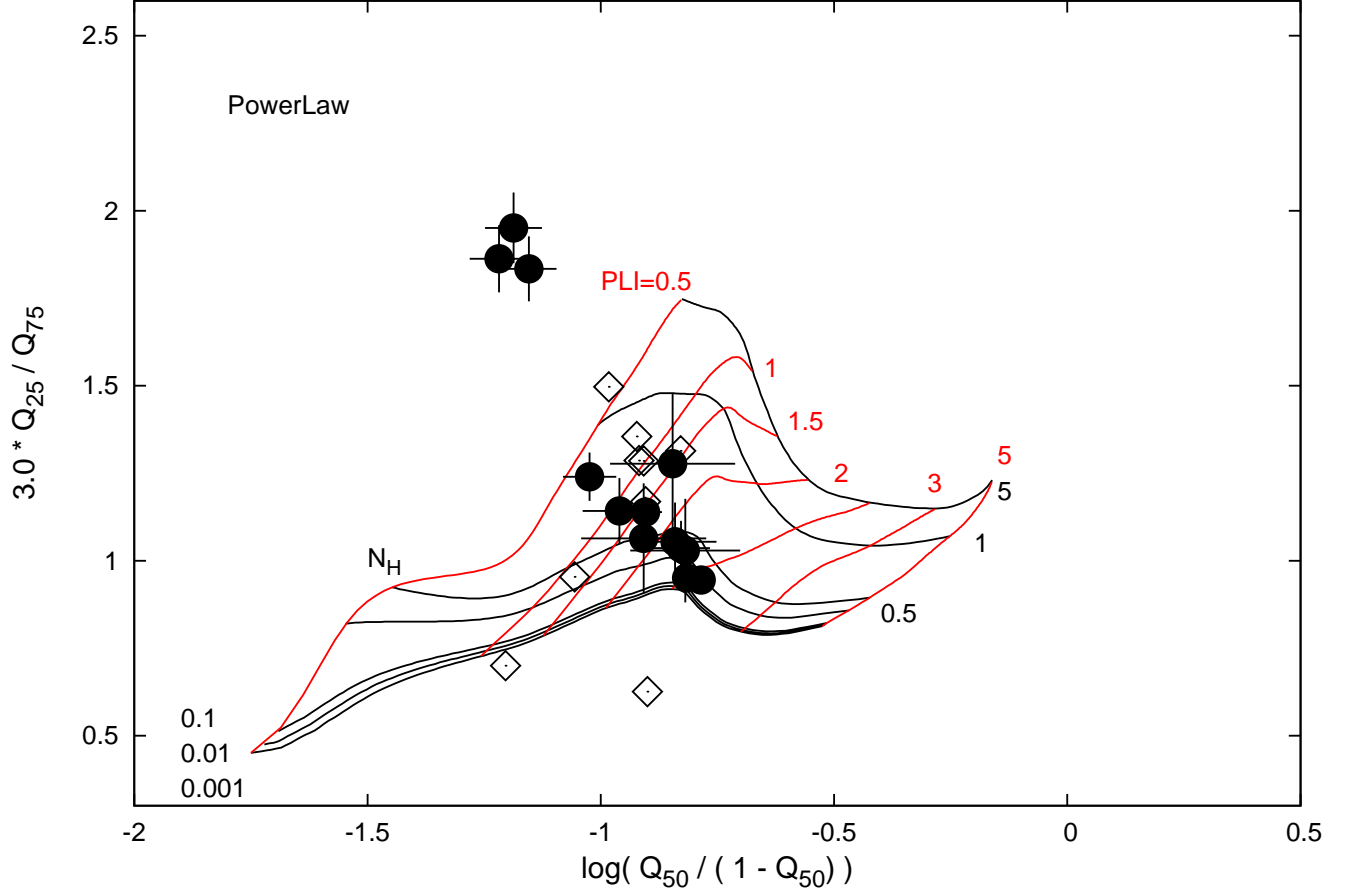


Fig. 10.— Quantile plot for the detected sources in NGC 7793 using a power law model. The plot symbols are defined in the caption of Figure 9: the units for  $N_H$  are  $10^{22} \text{ cm}^{-2}$  and the power law index “PLI” is defined as  $E^{-PLI}$ . See Section 3.3 and Figure 9 for a description of the model, the groupings of points and further details.

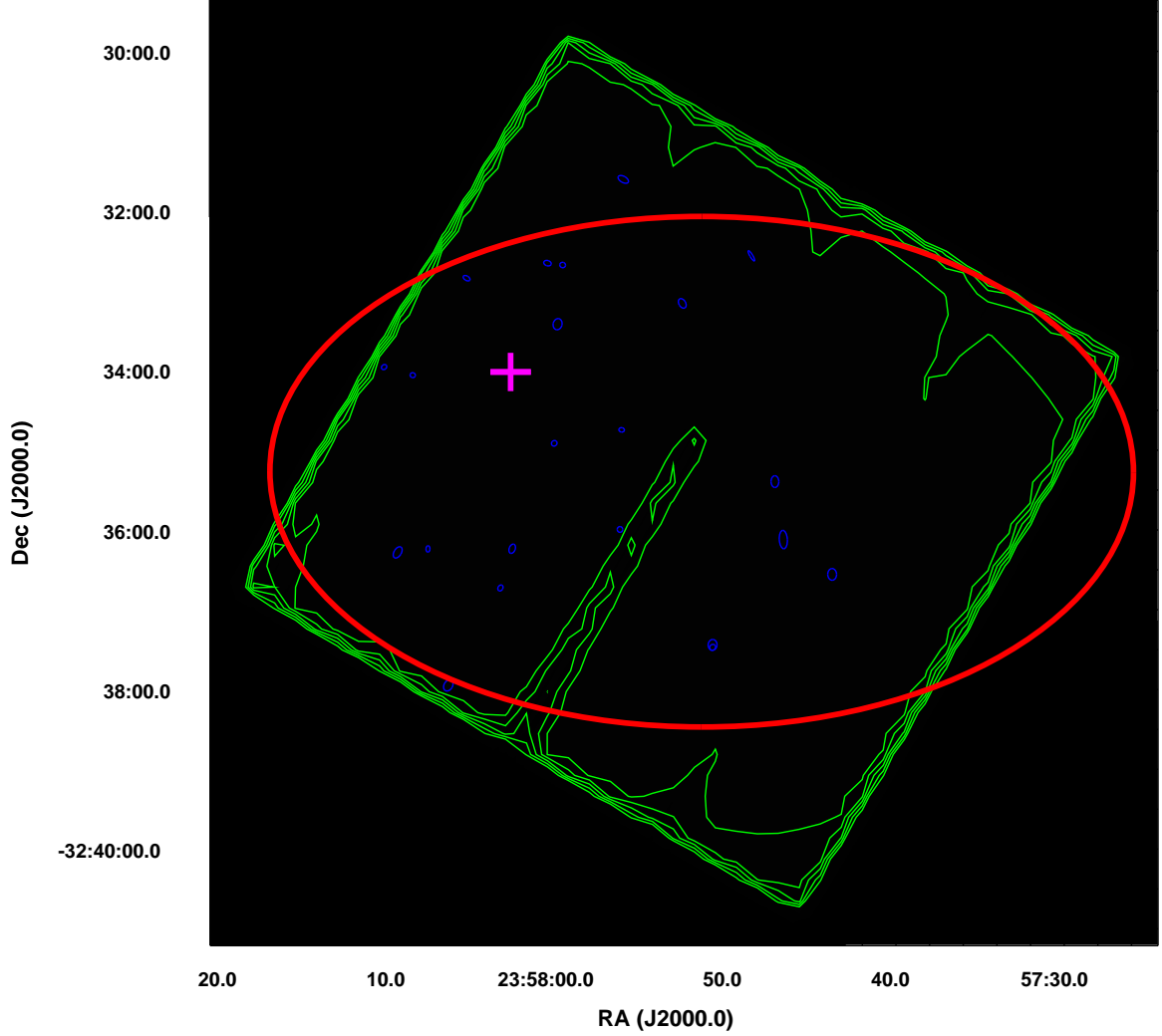


Fig. 11.— Contour plot showing levels of exposure for the ACIS-S chip during the observation of NGC 7793. The green contours depict levels corresponding to 90%, 85%, 80%, 75% and 70% (respectively) of the peak exposure value of  $\sim 3 \times 10^7 \text{ cm}^{-2} \text{ s counts photon}^{-1}$ . Similar to Figure 1, the detected sources are indicated with blue ellipses, the red ellipse indicates the optical extent of NGC 7793 and the magenta cross indicates the aimpoint of the observation. We argue that the lack of detections of discrete X-ray sources in the northwestern quadrant of NGC 7793 cannot be explained by simply a significantly lower effective exposure in that portion of the ACIS-S3 chip. See Section 3.5.

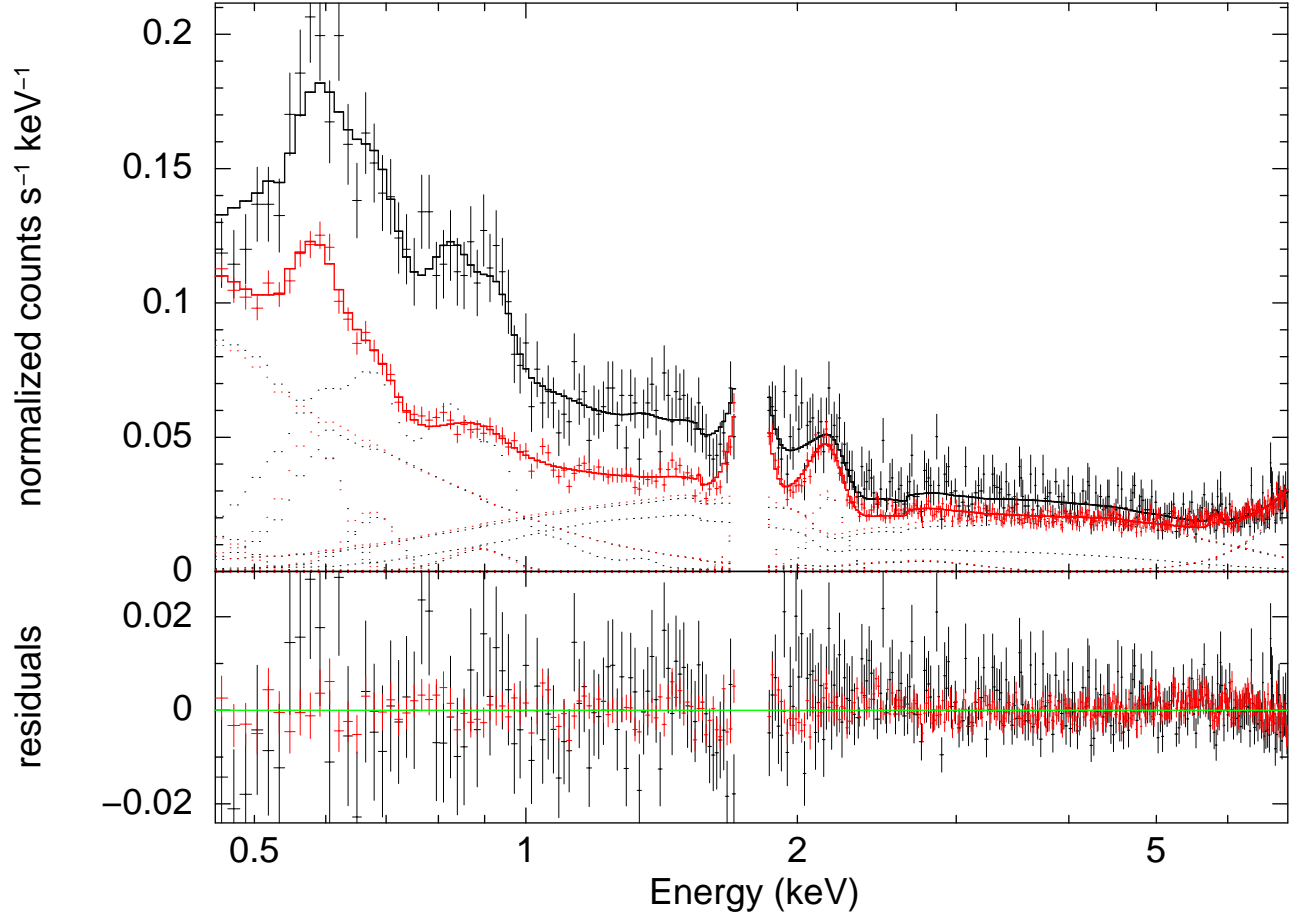


Fig. 12.— Extracted spectrum of the diffuse X-ray emission of NGC 7793. The source+background spectrum is shown in black while the background spectrum is shown in red. Dotted lines represent the individual model components. The spectra have been fit using the VAPEC model: the column density has been fixed at the value corresponding to the Galactic column density toward NGC 7793 ( $N_H = 1.15 \times 10^{20} \text{ cm}^{-2}$ ). The background spectrum contained a large fluorescent feature at 1.78 keV: data was excised at this location. See Section 4.

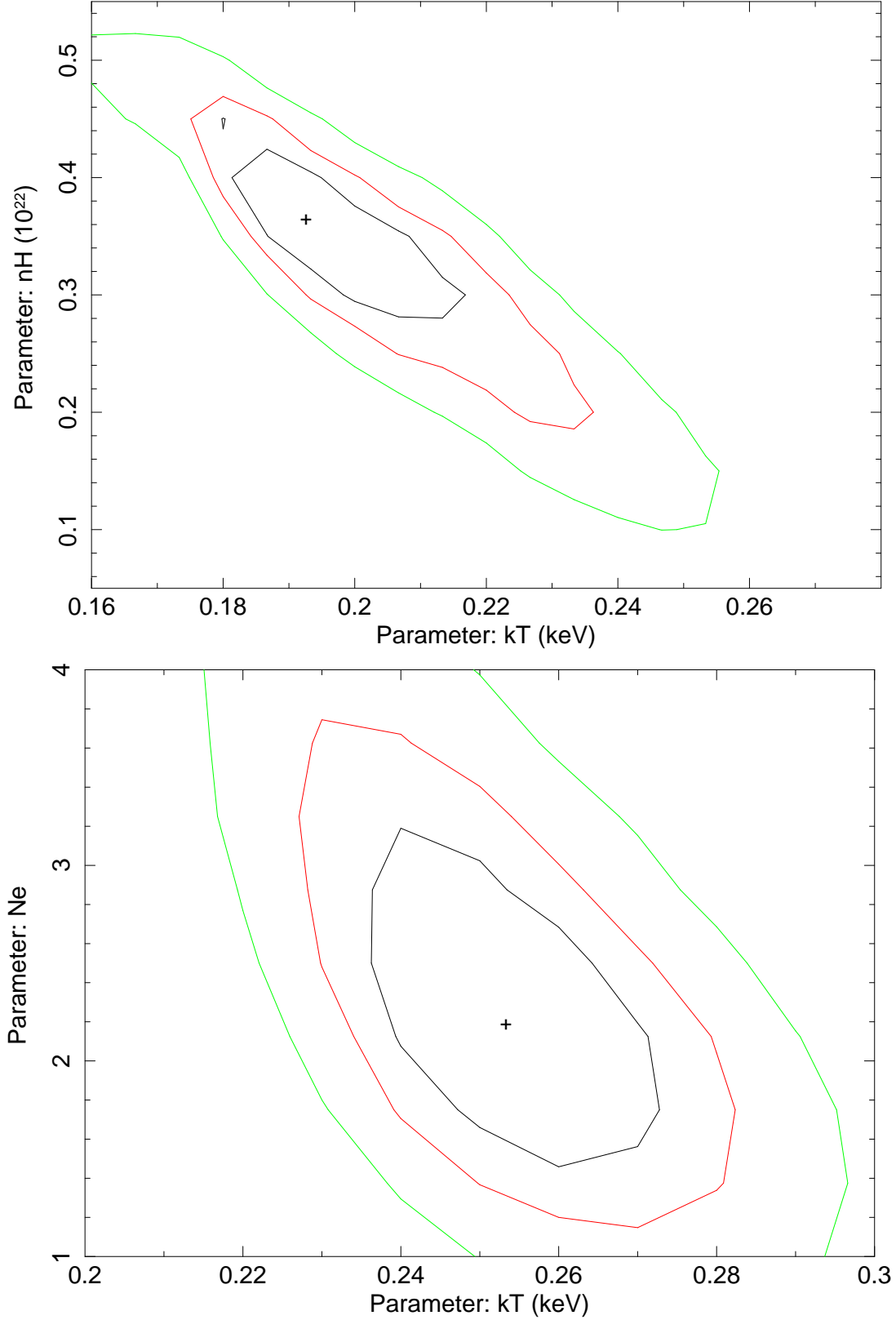


Fig. 13.— (top) Confidence contours for fit (as shown in Figure 12) to the extracted spectrum of the diffuse emission; (bottom) contours for the fixed  $N_{\text{H}}$  VAPEC model. The contours are plotted at the same levels as in Figure 3. For neon, we have plotted this parameter in units of solar abundance. See Section 4.

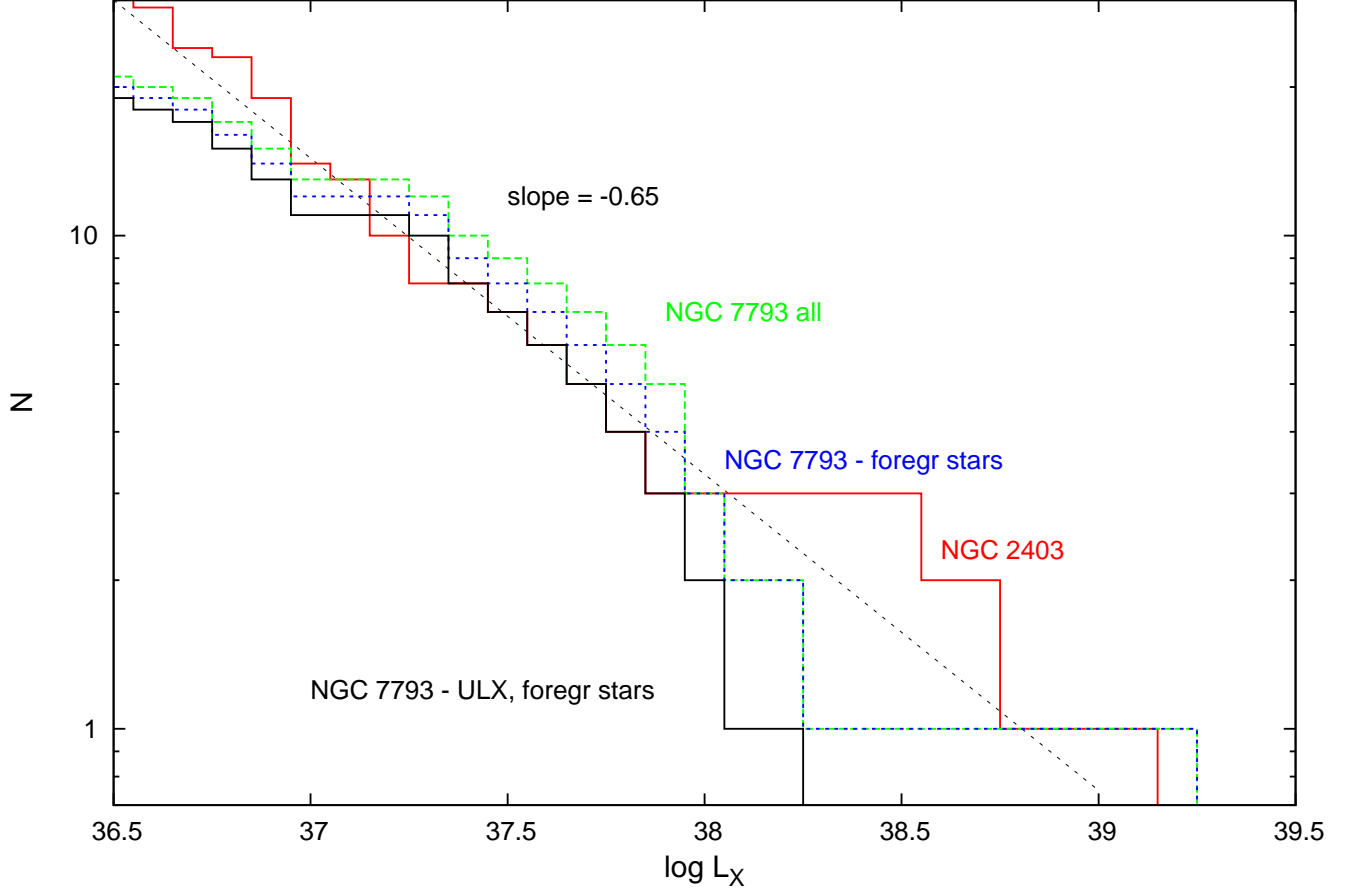


Fig. 14.— Luminosity function for all discrete sources within the optical extent of NGC 7793 (green dashed online), all sources except the two known foreground stars (blue dashed online), and all sources after excluding the foreground stars and the ULX (black line). The luminosity function of the discrete sources in the galaxy NGC 2403 (Schlegel & Pannuti 2003) is shown for comparison (red line online). The dashed line represents a slope of  $-0.65$ . See Section 5.

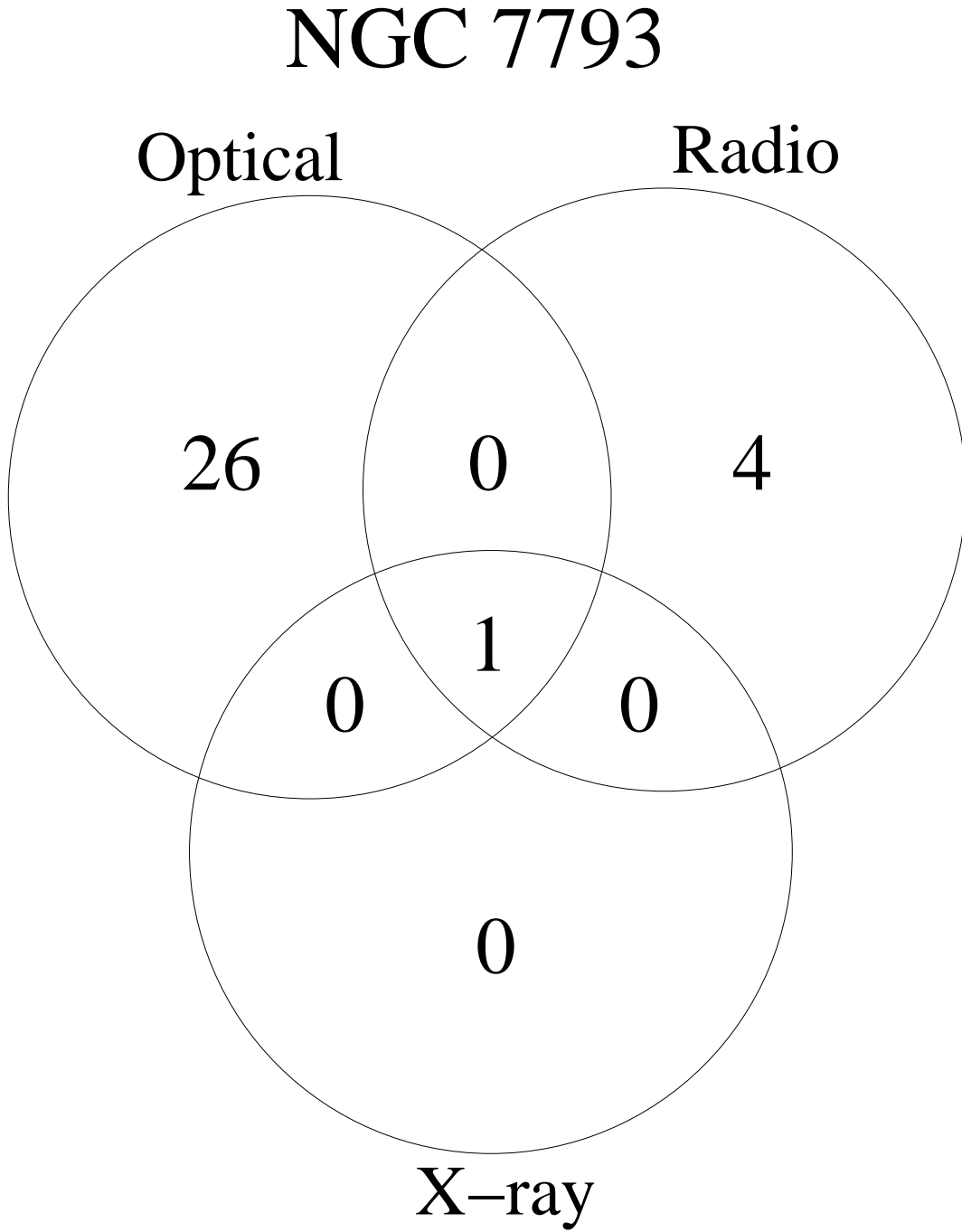


Fig. 15.— Venn diagram showing the overlap of the detections of SNRs in NGC 7793 at X-ray, optical and radio wavelengths. See Section 6.

Table 1. Summary of Gross Properties and *Chandra* Observation of NGC 7793

Property		Reference
Nucleus		
RA (J2000.0)	$23^h 57^m 49^s.83$	(1)
Dec (J2000.0)	$-32^\circ 35' 27''.7$	(1)
Galactic Longitude $l$ ( $^\circ$ )	4.52	(1)
Galactic Latitude $b$ ( $^\circ$ )	$-77.17$	(1)
Galaxy		
Observed Diameter $D_{25}$ (arcmin)	9.2	(2)
Axial Ratio $d/D$	0.70	(2)
Hubble Type	SA(s)d HII	(1)
HI Mass ( $M_\odot$ )	$9.1 \times 10^8$	(3)
Distance (Mpc)	3.91	(4)
Inclination $i$ ( $^\circ$ )	50	(2)
Pointed <i>Chandra</i> Observation		
RA (J2000)	$23^h 58^m 02^s.9$	
Dec (J2000)	$-32^\circ 34' 01''.3$	
ObsID/SeqID	3954/600328	
Roll Angle (deg)	30.2	
Effective Exposure Time (sec)	49094	

References. — (1) NED, (2) Tully (1988), (3) This value has been calculated based on the HI mass of NGC 7793 that was calculated by Carignan & Puche (1990) to be  $6.8 \times 10^8 M_\odot$  for an assumed distance to the galaxy of 3.38 Mpc. We have scaled this value based on our different assumed distance to the galaxy. (4) Karachentsev et al. (2003).



Table 2. Properties of *Chandra*-Detected Sources in the NGC 7793 Field

Source	R.A. (J2000.0)	Decl. (J2000.0)	Net Count Rate ( $\pm$ Error)	Absorbed Flux ( $\times 10^{-15}$ )	Unabsorbed Flux ( $\times 10^{-15}$ )	Unabsorbed Luminosity ( $\times 10^{37}$ )	Significance ( $\sigma$ )
CXOU J235743.8–323633	23 57 43.8	–32 36 33.6	$4.71(\pm 0.98) \times 10^{-4}$	$4.78(\pm 0.99)$	$5.02(\pm 1.10)$	$0.92(\pm 0.20)$	4.6
CXOU J235746.7–323607	23 57 46.7	–32 36 07.4	$5.50(\pm 0.33) \times 10^{-3}$	$55.8(\pm 3.4)$	$57.8(\pm 3.5)$	$10.6(\pm 6.4)$	18.5
CXOU J235747.2–323523	23 57 47.2	–32 35 23.8	$4.79(\pm 0.98) \times 10^{-4}$	$4.86(\pm 0.99)$	$5.03(\pm 1.03)$	$0.92(\pm 0.19)$	4.5
CXOU J235748.6–323234	23 57 48.6	–32 32 34.0	$1.41(\pm 0.77) \times 10^{-4}$	$1.43(\pm 0.79)$	$1.48(\pm 0.82)$	$0.27(\pm 0.15)$	2.9
CXOU J235750.9–323728	23 57 50.9	–32 37 28.5	$3.24(\pm 0.26) \times 10^{-3}$	$32.9(\pm 2.6)$	$34.1(\pm 2.7)$	$6.24(\pm 0.49)$	11.3
CXOU J235750.9–323726	23 57 50.9	–32 37 26.6	$6.61(\pm 0.12) \times 10^{-2}$	$671(\pm 12)$	$695(\pm 13)$	$127(\pm 2)$	59.7
CXOU J235752.7–323309	23 57 52.7	–32 33 09.8	$4.46(\pm 0.30) \times 10^{-3}$	$45.3(\pm 3.1)$	$46.9(\pm 3.2)$	$8.58(\pm 0.59)$	23.6
CXOU J235756.2–323136	23 57 56.2	–32 31 36.5	$3.08(\pm 1.02) \times 10^{-4}$	$3.13(\pm 1.04)$	$3.24(\pm 1.07)$	$0.59(\pm 0.20)$	4.8
CXOU J235756.3–323444	23 57 56.3	–32 34 44.9	$3.03(\pm 1.02) \times 10^{-4}$	$3.07(\pm 1.04)$	$3.18(\pm 1.08)$	$0.58(\pm 0.20)$	6.4
CXOU J235756.4–323559	23 57 56.4	–32 35 59.8	$1.31(\pm 0.16) \times 10^{-3}$	$13.3(\pm 1.7)$	$13.8(\pm 1.7)$	$2.52(\pm 0.31)$	12.1
CXOU J235759.8–323240	23 57 59.8	–32 32 40.9	$1.66(\pm 0.18) \times 10^{-3}$	$16.8(\pm 1.9)$	$17.4(\pm 2.0)$	$3.18(\pm 0.37)$	14.9
CXOU J235800.1–323325	23 58 00.1	–32 33 25.4	$9.70(\pm 1.41) \times 10^{-4}$	$9.84(\pm 1.46)$	$10.2(\pm 1.5)$	$1.87(\pm 0.27)$	7.4
CXOU J235800.3–323455	23 58 00.3	–32 34 55.0	$1.09(\pm 0.15) \times 10^{-3}$	$11.1(\pm 1.6)$	$11.5(\pm 1.6)$	$2.10(\pm 0.29)$	10.3
CXOU J235800.7–323239	23 58 00.7	–32 32 39.5	$3.40(\pm 0.11) \times 10^{-4}$	$3.45(\pm 1.08)$	$3.57(\pm 1.12)$	$0.65(\pm 0.20)$	5.5
CXOU J235802.8–323614	23 58 02.8	–32 36 14.3	$2.76(\pm 0.24) \times 10^{-3}$	$28.0(\pm 2.4)$	$29.0(\pm 2.5)$	$5.31(\pm 0.46)$	20.6
CXOU J235803.5–323643	23 58 03.5	–32 36 43.8	$1.24(\pm 0.16) \times 10^{-3}$	$12.6(\pm 1.6)$	$13.0(\pm 1.7)$	$2.38(\pm 0.31)$	10.9
CXOU J235805.5–323250	23 58 05.5	–32 32 50.8	$2.04(\pm 0.87) \times 10^{-4}$	$2.07(\pm 0.89)$	$2.14(\pm 0.92)$	$0.39(\pm 0.17)$	3.7
CXOU J235806.6–323757	23 58 06.6	–32 37 57.1	$8.48(\pm 0.42) \times 10^{-3}$	$86.0(\pm 4.3)$	$89.1(\pm 4.4)$	$16.3(\pm 0.8)$	21.6
CXOU J235807.8–323614	23 58 07.8	–32 36 14.4	$2.08(\pm 0.88) \times 10^{-4}$	$2.11(\pm 0.89)$	$2.19(\pm 0.92)$	$0.40(\pm 0.17)$	3.9
CXOU J235808.7–323403	23 58 08.7	–32 34 03.7	$5.11(\pm 0.32) \times 10^{-3}$	$51.9(\pm 3.3)$	$53.7(\pm 3.4)$	$9.82(\pm 0.62)$	31.5
CXOU J235809.6–323617	23 58 09.6	–32 36 17.0	$4.11(\pm 0.92) \times 10^{-4}$	$4.17(\pm 0.93)$	$4.32(\pm 0.96)$	$0.79(\pm 0.18)$	5.7
CXOU J235810.4–323357	23 58 10.4	–32 33 57.6	$2.47(\pm 0.22) \times 10^{-3}$	$25.1(\pm 2.3)$	$26.0(\pm 2.4)$	$4.76(\pm 0.44)$	19.4

Table 2—Continued

			Net	Absorbed	Unabsorbed	Unabsorbed	
	R.A.	Decl.	Count	Flux	Flux	Luminosity	Significance
Source	(J2000.0)	(J2000.0)	Rate ( $\pm$ Error)	( $\times 10^{-15}$ )	( $\times 10^{-15}$ )	( $\times 10^{37}$ )	( $\sigma$ )

Note. — Units of Right Ascension are hours, minutes and seconds and units of Declination are degrees, arcminutes and arcseconds. Net count rates are in units of counts  $\text{s}^{-1}$  and refer to the number of counts extracted above background in the 0.2-10.0 keV energy range within the source extract region (for the entire observation with an effective exposure time of 49094 seconds). Fluxes (both absorbed and unabsorbed) are in units of  $\text{ergs cm}^{-2} \text{s}^{-1}$  and have been computed assuming a foreground column density  $N_H = 1.15 \times 10^{20} \text{ cm}^{-2}$  and adopting a power law model with a photon index  $\Gamma=1.5$ . Unabsorbed luminosities are in units of  $\text{ergs s}^{-1}$  and have been calculated assuming a distance  $d = 3.91 \text{ Mpc}$  to NGC 7793.

Table 3. Multi-Wavelength Counterparts of *Chandra* Sources in the NGC 7793 Field

Source	Counterparts
CXOU J235743.8–323633	D22
CXOU J235746.7–323607	P10, R3
CXOU J235747.2–323523	N7793-S11, D40
CXOU J235748.6–323234	P6, Star (USNO 0574–1250312), H18(?)
CXOU J235750.9–323728	P13?
CXOU J235750.9–323726	P13?
CXOU J235752.7–323309	P7, Star (USNO 0574–1250339)
CXOU J235800.1–323325	P8, N7793-S26
CXOU J235802.8–323614	P11?
CXOU J235803.5–323643	P11?
CXOU J235808.7–323403	P9

Note. — The listed counterparts have been taken from the following references: H and D – HII regions identified by Hodge (1969) and Davoust & de Vaucouleurs (1980), respectively; S – optically-identified SNRs identified by Blair & Long (1997); P – X-ray sources detected by the *ROSAT* PSPC and presented by RP99; R – candidate radio SNRs identified by Pannuti et al. (2002). The identifications of stellar counterparts are made based on the USNO-B catalog (Monet et al. 2003). Sources not listed do not have any counterparts at other wavelengths.

Table 4. Spectral Fits for the Brightest Sources<sup>a</sup>

Source	Model	Energy	kT or $\Gamma$	Col Density	Norm	Gauss	EqW	$\chi^2/\text{Degrees}$
		Range	Value	$N_{\text{H}}$		Line Energy		of Freedom
CXOU J235746.7–323607	Brems	0.5–6.0	$1.55^{+2.82}_{-0.89}$	$0.32^{+0.66}_{-0.22}$	$1.4^{(+6.5)}_{(-0.8)}\times 10^{-5}$	G1: 0.94f	$110^{+75}_{-38}$	17.4/21=0.82
						G2: 1.47f	$66^{+70}_{-62}$	
	DiskBB	0.5–6.0	$0.72^{+0.47}_{-0.30}$	<0.68	$4.4^{(+6.1)}_{(-3.8)}\times 10^{-3}$	G1: 0.94f	$109^{+84}_{-12}$	16.7/21=0.80
						G2: 1.47f	$65^{+50}_{-48}$	
	PowLaw	0.5–6.0	$2.87^{+2.03}_{-0.80}$	$0.47^{+0.83}_{-0.17}$	$1.4^{(+7.2)}_{(-0.9)}\times 10^{-5}$	G1: 0.94f	$118^{+90}_{-25}$	18.1/20=0.91
						G2: 1.46f	<68	
CXOU J235750.9–323726	PowLaw-f	0.5–6.0	$1.69^{+0.51}_{-0.41}$	0.0115f	$1.4^{(+7.2)}_{(-0.9)}\times 10^{-5}$	G1: 0.94f	$111^{+74}_{-74}$	18.1/20=0.91
						G2: 1.46f	$102^{+76}_{-75}$	
	APEC	0.5–6.0	$0.78^{+0.18}_{-0.17}$	$0.96^{+0.21}_{-0.23}$	$4.45^{(+2.17)}_{(-1.77)}\times 10^{-5}$	...	...	23.23/22=1.06
CXOU J235750.9–323726	Brems	0.3–7.0	>14	$0.12^{+0.07}_{-0.05}$	$6.4^{(+1.6)}_{(-1.1)}\times 10^{-5}$	G1: 0.59f	<48	66.8/65=1.03
						G2: 0.82f	$42^{+55}_{-39}$	
						G3: 0.99f	<34	
	DiskBB	0.3–7.0	$1.83^{+0.16}_{-0.14}$	$0.07^{+0.03}_{-0.02}$	$6.0^{(+5.5)}_{(-3.2)}\times 10^{-4}$	G1: 0.82f	<132	66.3/65=1.02
						G2: 0.82f	$45^{+50}_{-40}$	
						G3: 0.99f	<30	

Table 4—Continued

Source	Model	Energy Range	kT or $\Gamma$ Value	Col Density $N_H$	Norm	Gauss Line Energy	EqW	$\chi^2$ /Degrees of Freedom
CXOU J235806.6–323757	PowLaw	0.3–7.0	$1.4^{+0.20}_{-0.18}$	$0.17^{+0.09}_{-0.07}$	$3.6(^{+0.6}_{-0.7}) \times 10^{-5}$	G1: 0.60f G2: 0.82f G3: 0.99f	<48 $45^{+63}_{-40}$ <69	78.3/68=1.15
	Brems	0.5–6.0	$1.98^{+1.24}_{-0.89}$	$0.21^{+0.21}_{-0.12}$	$2.7(^{+2.7}_{-0.9}) \times 10^{-5}$	G1: 0.67f G2: 0.83f	$118^{+170}_{-90}$ $120^{+95}_{-75}$	24.9/29=0.86
	Brems-f	0.5–6.0	$6.42^{+15.72}_{-3.08}$	0.0115f	$2.7(^{+2.7}_{-0.9}) \times 10^{-5}$	G1: 0.67f G2: 0.83f	<51 $45^{+27}_{-27}$	24.9/29=0.86
	DiskBB	0.5–6.0	$0.83^{+0.30}_{-0.22}$	<0.08	$5.3(^{+13.4}_{-3.6}) \times 10^{-3}$	G1: 0.83f	$51^{+39}_{-31}$	30.8/31=0.99
	PowLaw	0.5–6.0	$2.45^{+0.65}_{-0.45}$	$0.29^{+0.17}_{-0.16}$	$2.5(^{+1.5}_{-0.8}) \times 10^{-5}$	G1: 0.67f G2: 0.83f	$122^{+73}_{-42}$ $118^{+181}_{-75}$	23.9/31=0.77
CXOU J235808.7–323403	APEC	0.5-2.5	$0.83^{+0.48}_{-0.65}$	$0.16^{+0.33}_{-0.08}$	$5.6(\pm 4.5) \times 10^{-4}$	...	...	16.5/15=1.10
	APEC-f	0.5-2.5	$0.62^{+0.32}_{-0.12}$	0.0115f	$1.7(\pm 1.4) \times 10^{-6}$	...	...	21.4/16=1.34
	DiskBB	0.5-2.5	$0.20^{+0.18}_{-0.09}$	$0.28^{+0.24}_{-0.18}$	$1.8 \pm 1.4$	...	...	19.2/15=1.28

<sup>a</sup>An “f” after a number or label indicates that the parameter was fixed at that value during the fit. “Energy Range” is in units of keV. Parameter values are as follows: Power Law (“PowLaw”): Photon Index  $\Gamma$  defined such that  $E^{-\Gamma}$ ; Bremsstrahlung (“Brems”): temperature  $kT$  in keV and DiskBB (multi-color disk model) temperature  $kT_{\text{in}}$  in keV. The normalizations are defined as follows – Power Law: photons/keV/cm<sup>2</sup>/s at 1 keV; Bremsstrahlung:  $3.02 \times 10^{-15} / (4\pi d^2) \int n_e n_i dV$  where  $d$  is the distance to the source in cm and  $n_e$  and  $n_i$  are the electron and ion densities respectively in cm<sup>-3</sup>; DiskBB:  $(R_{\text{in}}/D)^2 \cos \theta$ , where  $R_{\text{in}}$  is the inner disk radius in km,  $D$  is the distance to the source (in units of 10 kpc) and  $\theta$  is the angle of the disk. The column density  $N_{\text{H}}$  is in units of 10<sup>22</sup> cm<sup>-2</sup>. Finally, “EqW” is the Gaussian Equivalent Width in eV. In this table we are presenting the best fits derived from the models that we used and not necessarily every model that we used. For details of the spectral analysis of these sources, see Section 3.1.

Table 5. Quantile Values for Point Sources

Source	$Q_{25}$	$Q_{50}$	$Q_{75}$	$\log(Q_{50}/(1-Q_{50}))$	$3Q_{25}/Q_{75}$
CXOU J235743.8-323633	0.096( $\pm 0.004$ )	0.132( $\pm 0.011$ )	0.280( $\pm 0.018$ )	-0.819( $\pm 0.118$ )	1.029( $\pm 0.148$ )
CXOU J235746.7-323607	0.077( $\pm 0.001$ )	0.129( $\pm 0.001$ )	0.223( $\pm 0.005$ )	-0.828( $\pm 0.062$ )	1.036( $\pm 0.078$ )
CXOU J235747.2-323523	0.051( $\pm 0.004$ )	0.061( $\pm 0.003$ )	0.079( $\pm 0.002$ )	-1.187( $\pm 0.061$ )	1.951( $\pm 0.101$ )
CXOU J235748.6-323234	0.028( $\pm 0.067$ )	0.059( $\pm 0.038$ )	0.122( $\pm 0.014$ )	-1.204( $\pm 0.409$ )	0.700( $\pm 0.238$ )
CXOU J235750.9-323728	0.085( $\pm 0.000$ )	0.141( $\pm 0.001$ )	0.269( $\pm 0.001$ )	-0.785( $\pm 0.028$ )	0.945( $\pm 0.034$ )
CXOU J235750.9-323726	0.082( $\pm 0.000$ )	0.132( $\pm 0.000$ )	0.258( $\pm 0.000$ )	-0.816( $\pm 0.018$ )	0.951( $\pm 0.021$ )
CXOU J235752.7-323309	0.080( $\pm 0.004$ )	0.126( $\pm 0.001$ )	0.228( $\pm 0.008$ )	-0.841( $\pm 0.089$ )	1.054( $\pm 0.112$ )
CXOU J235756.2-323136	0.089( $\pm 0.011$ )	0.107( $\pm 0.030$ )	0.197( $\pm 0.143$ )	-0.923( $\pm 0.311$ )	1.355( $\pm 0.456$ )
CXOU J235756.3-323444	0.088( $\pm 0.027$ )	0.129( $\pm 0.044$ )	0.201( $\pm 0.115$ )	-0.829( $\pm 0.272$ )	1.314( $\pm 0.431$ )
CXOU J235756.4-323559	0.073( $\pm 0.010$ )	0.108( $\pm 0.004$ )	0.170( $\pm 0.014$ )	-0.918( $\pm 0.125$ )	1.286( $\pm 0.175$ )
CXOU J235759.8-323240	0.065( $\pm 0.007$ )	0.110( $\pm 0.004$ )	0.183( $\pm 0.016$ )	-0.908( $\pm 0.134$ )	1.064( $\pm 0.157$ )
CXOU J235800.1-323325	0.049( $\pm 0.003$ )	0.066( $\pm 0.001$ )	0.081( $\pm 0.001$ )	-1.154( $\pm 0.059$ )	1.834( $\pm 0.093$ )
CXOU J235800.3-323455	0.046( $\pm 0.003$ )	0.057( $\pm 0.002$ )	0.074( $\pm 0.002$ )	-1.218( $\pm 0.063$ )	1.863( $\pm 0.096$ )
CXOU J235800.7-323239	0.076( $\pm 0.034$ )	0.110( $\pm 0.024$ )	0.176( $\pm 0.274$ )	-0.908( $\pm 0.444$ )	1.285( $\pm 0.629$ )
CXOU J235802.8-323614	0.060( $\pm 0.002$ )	0.099( $\pm 0.006$ )	0.157( $\pm 0.005$ )	-0.960( $\pm 0.079$ )	1.142( $\pm 0.094$ )
CXOU J235803.5-323643	0.073( $\pm 0.007$ )	0.111( $\pm 0.010$ )	0.186( $\pm 0.045$ )	-0.904( $\pm 0.192$ )	1.169( $\pm 0.248$ )
CXOU J235805.5-323250	0.081( $\pm 0.098$ )	0.112( $\pm 1.079$ )	0.388( $\pm 0.671$ )	-0.900( $\pm 0.998$ )	0.626( $\pm 0.694$ )
CXOU J235806.6-323757	0.068( $\pm 0.000$ )	0.111( $\pm 0.001$ )	0.179( $\pm 0.001$ )	-0.904( $\pm 0.035$ )	1.139( $\pm 0.044$ )
CXOU J235807.8-323614	0.069( $\pm 0.035$ )	0.094( $\pm 0.022$ )	0.139( $\pm 0.346$ )	-0.983( $\pm 0.496$ )	1.497( $\pm 0.755$ )
CXOU J235808.7-323403	0.057( $\pm 0.001$ )	0.087( $\pm 0.002$ )	0.137( $\pm 0.003$ )	-1.024( $\pm 0.057$ )	1.240( $\pm 0.069$ )
CXOU J235809.6-323617	0.055( $\pm 0.012$ )	0.081( $\pm 0.046$ )	0.174( $\pm 0.289$ )	-1.056( $\pm 0.593$ )	0.954( $\pm 0.536$ )
CXOU J235810.4-323357	0.079( $\pm 0.007$ )	0.125( $\pm 0.002$ )	0.185( $\pm 0.025$ )	-0.846( $\pm 0.134$ )	1.277( $\pm 0.202$ )

Note. —  $Q_{25}$ ,  $Q_{50}$  and  $Q_{75}$  are all defined in Section 3.3.

Table 6. Unabsorbed Luminosities of Common Discrete X-ray Sources Detected by  
*ROSAT* and *Chandra*<sup>a</sup>

<i>ROSAT</i> Source	Unabsorbed $L_{\text{Einstein}}$	Unabsorbed $L_{\text{PSPC}}$	<i>Chandra</i> Source	Unabsorbed $L_{\text{Chandra}}$
P10	...	$1.35(\pm 0.14) \times 10^{38}$	CXOU J235746.7–323607	$4.79(\pm 0.28) \times 10^{37}$
P6	...	$3.14(\pm 0.71) \times 10^{37}$	CXOU J235748.6–323234	$1.23(\pm 0.70) \times 10^{36}$
P7	...	$4.20(\pm 0.88) \times 10^{37}$	CXOU J235752.7–323309	$3.88(\pm 0.26) \times 10^{37}$
P8	...	$5.43(\pm 0.88) \times 10^{37}$	CXOU J235800.1–323325	$8.43(\pm 1.22) \times 10^{36}$
P9	...	$8.57(\pm 1.05) \times 10^{37}$	CXOU J235808.7–323403	$4.45(\pm 0.28) \times 10^{37}$
P13	$7.43(\pm 1.49) \times 10^{38}$	$7.62(\pm 0.25) \times 10^{38}$	CXOU J235750.9–323726	$5.74(\pm 0.11) \times 10^{38}$
			CXOU J235750.9–323728	$2.82(\pm 0.22) \times 10^{37}$
P11	...	$3.14(\pm 0.71) \times 10^{37}$	CXOU J235802.8–323614	$2.40(\pm 0.20) \times 10^{37}$
			CXOU J235803.5–323643	$1.08(\pm 0.14) \times 10^{37}$

<sup>a</sup>The luminosities have been calculated by converting count rates (over the range of 0.12–2.48 keV) to fluxes using a power-law model (with a photon index  $\Gamma=1.5$ ) and assuming a column density  $N_H=1.15 \times 10^{20} \text{ cm}^{-2}$ . The units of the luminosities are  $\text{ergs s}^{-1}$ .



Table 7. Spectral Fits to Diffuse Emission Spectrum<sup>a</sup>

Model	$N_{\text{H}}$ ( $10^{22} \text{ cm}^{-2}$ )	Parameter <sup>b</sup>	Norm	Flux or EqW <sup>c</sup>	Unabsorbed Flux	$\chi^2/\text{Degrees}$ of Freedom
APEC	$0.368^{+0.051}_{-0.052}$	$0.193^{+0.013}_{-0.009}$	$1.0 \pm 0.1 \times 10^{-3}$	$5.4 \times 10^{-13}$	$17.4 \times 10^{-13}$	763.58/730=1.05
+ Power Law	...	$1.15^{+0.18}_{-0.17}$	$6.1 \pm 0.6 \times 10^{-5}$	$0.8 \times 10^{-13}$	$4.9 \times 10^{-13}$	...
VAPEC	0.015f	$0.253^{+0.018}_{-0.015}$	$6.1^{+0.4}_{-0.8} \times 10^{-5}$	$5.4 \times 10^{-13}$	$5.5 \times 10^{-13}$	806.29/731=1.10
+ Ne	...	$2.23^{+0.74}_{-0.66}$	...	...	...	...
+ Power Law	...	$0.86^{+0.15}_{-0.14}$	$4.0^{+0.4}_{-0.3} \times 10^{-5}$	$4.5 \times 10^{-13}$	$4.6 \times 10^{-13}$	...
APEC-1	0.015f	$0.218^{+0.026}_{-0.016}$	$5.3 \pm 0.7 \times 10^{-5}$	$0.7 \times 10^{-13}$	$0.8 \times 10^{-13}$	764.08/727=1.05
+ APEC-2	...	$0.547^{+0.106}_{-0.117}$	$1.7 \pm 0.4 \times 10^{-5}$	$0.4 \times 10^{-13}$	$0.5 \times 10^{-13}$	...
+ Power Law	...	$0.75 \pm 0.14$	$3.8 \pm 0.3 \times 10^{-5}$	$1.0 \times 10^{-13}$	$1.1 \times 10^{-13}$	...
Multiple Gaussians	$0.226^{+0.195}_{-0.093}$	...	...	$5.5 \times 10^{-13}$	$7.3 \times 10^{-13}$	784.78/728=1.08
+ Gaussian-1	...	$0.603 \pm 0.015$	$2.5 \pm 0.4 \times 10^{-4}$	49	...	...
+ Gaussian-2	...	$0.751 \pm 0.009$	$5.9 \pm 0.9 \times 10^{-5}$	101	...	...
+ Gaussian-3	...	$0.896 \pm 0.013$	$3.0 \pm 0.5 \times 10^{-5}$	85	...	...
+ Power Law	...	$1.36^{+0.17}_{-0.15}$	$7.4 \pm 0.6 \times 10^{-5}$	$4.5 \times 10^{-13}$	$4.5 \times 10^{-13}$	...
Multiple Gaussians	0.015f	...	...	$1.9 \times 10^{-13}$	$2.0 \times 10^{-13}$	808.84/730=1.11
+ Gaussian-1	...	$0.608 \pm 0.011$	$4.3 \pm 0.8 \times 10^{-5}$	39	...	...
+ Gaussian-2	...	$0.753 \pm 0.015$	$1.8 \pm 0.3 \times 10^{-5}$	74	...	...
+ Gaussian-3	...	$0.890 \pm 0.020$	$1.3 \pm 0.2 \times 10^{-5}$	68	...	...
+ Power Law	...	$1.06 \pm 0.12$	$5.1 \pm 0.3 \times 10^{-5}$	$1.2 \times 10^{-13}$	$1.3 \times 10^{-13}$	...

<sup>a</sup>See Section 4 for a detailed description of these spectral fits. Also note that an “f” after a number indicates that the parameter was fixed at that value during the fit.

<sup>b</sup>‘Parameter’ is defined as follows for the various model components: for APEC, kT (keV); for the power law, the power law index  $\Gamma$ ; for a specific element, the abundance; for a Gaussian, the energy of the line center (keV).

<sup>c</sup>Flux units =  $\text{ergs s}^{-1} \text{ cm}^{-2}$  in 0.5-2 keV band; EqW = Equivalent width in eV. The flux in the background in the 0.5-2 keV band is  $3.4 \times 10^{-13} \text{ ergs s}^{-1} \text{ cm}^{-2}$ ; this flux has been removed from the computed model fluxes for the diffuse emission components.

Table 8. Comparison of Inferred Temperatures to Fits of the Diffuse Emission of Nearby Galaxies<sup>a</sup>

Galaxy	$kT_1$ (keV)	$kT_2$ (keV)	Reference
NGC 2403	$0.18 \pm 0.03$	$0.73 \pm 0.07$	Fraternali et al. (2002)
NGC 3184	$0.13^{+0.03}_{-0.03}$	$0.43^{+0.25}_{-0.22}$	Doane et al. (2004)
NGC 6946	$0.25^{+0.05}_{-0.02}$	$0.71^{+0.10}_{-0.08}$	Schlegel et al. (2003)
NGC 7793	$0.253^{+0.018}_{-0.015}$	$\dots$	This paper

<sup>a</sup>See Section 4.

Table 9. Comparison of Slopes of Luminosity Functions and Star Formation Rates of Nearby Galaxies<sup>a</sup>

Galaxy	Slope	Star Formation Rate		
	$\Gamma$	Reference	( $M_{\odot} \text{ yr}^{-1}$ )	Reference
NGC 2403	−0.59	(1)	0.30 <sup>b</sup>	(2)
M83 (NGC 5236)	−1.38±0.28	(3)	2.76	(4)
NGC 6946	−0.64	(5)	4	(6)
NGC 7793 <sup>c</sup>	∼−0.62±0.2, ∼−0.65±0.11	(7)	0.24	(8)
IC 5332	−1.30±0.31	(3)	0.08	(9)

Note. — References – (1) Schlegel & Pannuti (2003), (2) Sivan et al. (1990), (3) Kilgard et al. (2002), (4) Dopita et al. (2010), (5) Holt et al. (2003), (6) Sauty et al. (1998), (7) This paper, (8) Ferguson et al. (1996), (9) Meurer et al. (2006).

<sup>a</sup>See Section 5.

<sup>b</sup>To estimate the star formation rate for NGC 2403, we took the integrated  $H\alpha$  luminosity of this galaxy as estimated by Sivan et al. (1990) ( $L_{H\alpha} = 3.4 \times 10^{40} \text{ ergs sec}^{-1}$ ) and calculated a star formation rate using the relation derived by Kennicutt (1983) (that is, the total star formation rate in units of  $M_{\odot} \text{ yr}^{-1}$  is expressed as  $\text{SFR}(\text{total}) = L_{H\alpha} / 1.12 \times 10^{41} \text{ ergs sec}^{-1}$ ).

<sup>c</sup>As described in Section 5, a slope of  $\Gamma \sim -0.62 \pm 0.2$  was obtained for a fit to the complete function (though the residuals are large) while a slope of  $\Gamma \sim -0.65 \pm 0.11$  was obtained for a fit that excluded the ULX.